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(54) **LARYNGEAL STROBOSCOPE UTILIZING SOLID STATE LIGHT SOURCES**

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A61B 1/267 (2006.01)
A61B 1/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 1/2673*** (2013.01); ***A61B 1/000095*** (2022.02); ***A61B 1/045*** (2013.01);
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CPC A61B 1/2673; A61B 1/05; A61B 1/0676; A61B 1/0684; A61B 1/267; A61B 1/2676; A61B 1/063; A61B 1/0655; A61B 1/0661
See application file for complete search history.

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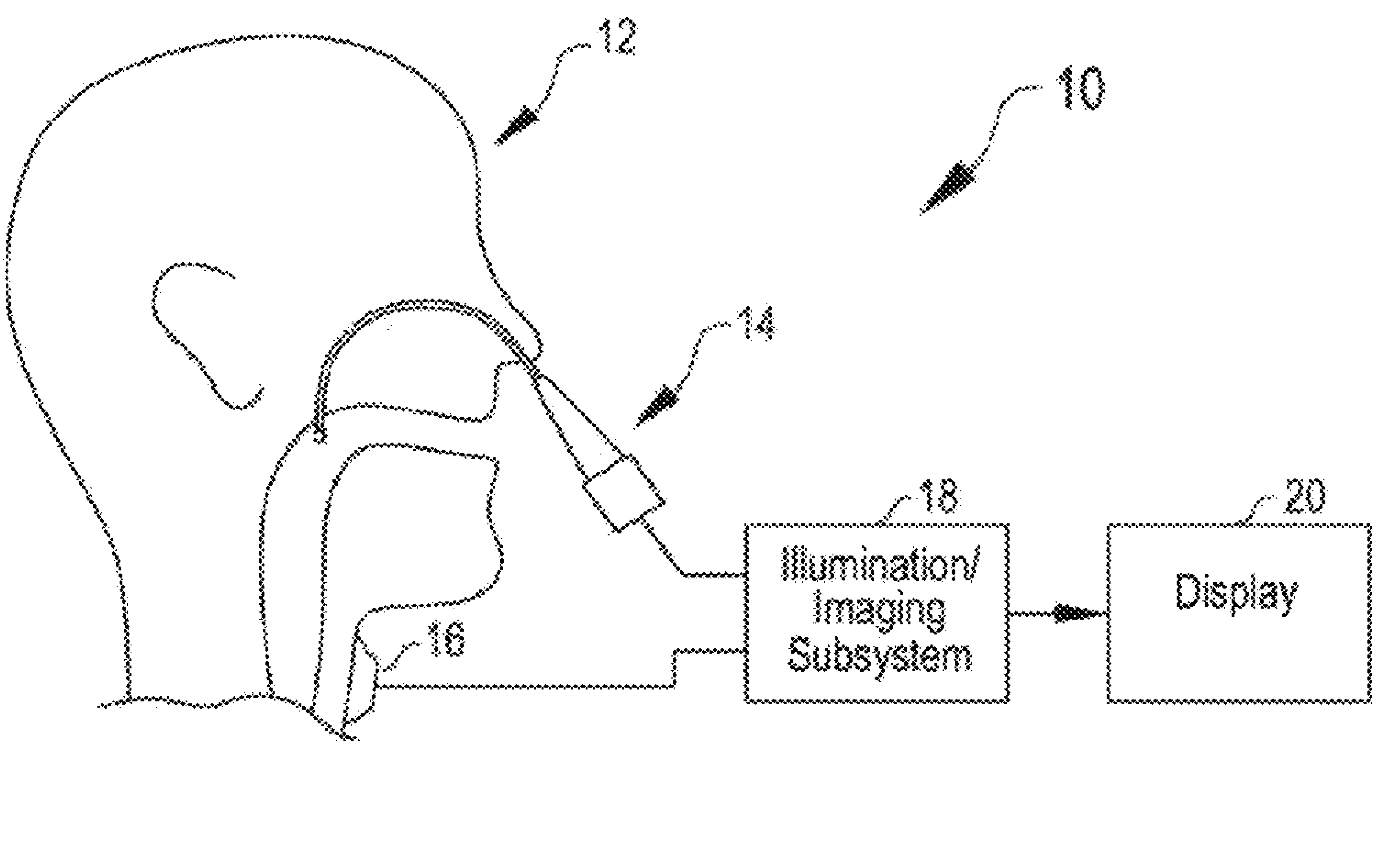
(57) **ABSTRACT**

Stroboscopic endoscopic systems and related methods employ intermittent energization of one or more light sources to generate a sequence of light flashes. A stroboscopic endoscope system includes an endoscope, an imaging device, a light source, a light transmission assembly, and a controller. The imaging device is configured for imaging an object illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the light source to the endoscope. The stroboscopic endoscopic systems and related methods employ approaches for increasing the amount of illumination light emitted by the endoscope.

14 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

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A61B 1/05	(2006.01)
A61B 1/06	(2006.01)
A61B 1/07	(2006.01)
A61B 1/12	(2006.01)

(52) **U.S. Cl.**
CPC ***A61B 1/05*** (2013.01); ***A61B 1/063*** (2013.01); ***A61B 1/0655*** (2022.02); ***A61B 1/0676*** (2013.01); ***A61B 1/0684*** (2013.01); ***A61B 1/07*** (2013.01); ***A61B 1/128*** (2013.01)

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FIG. 1

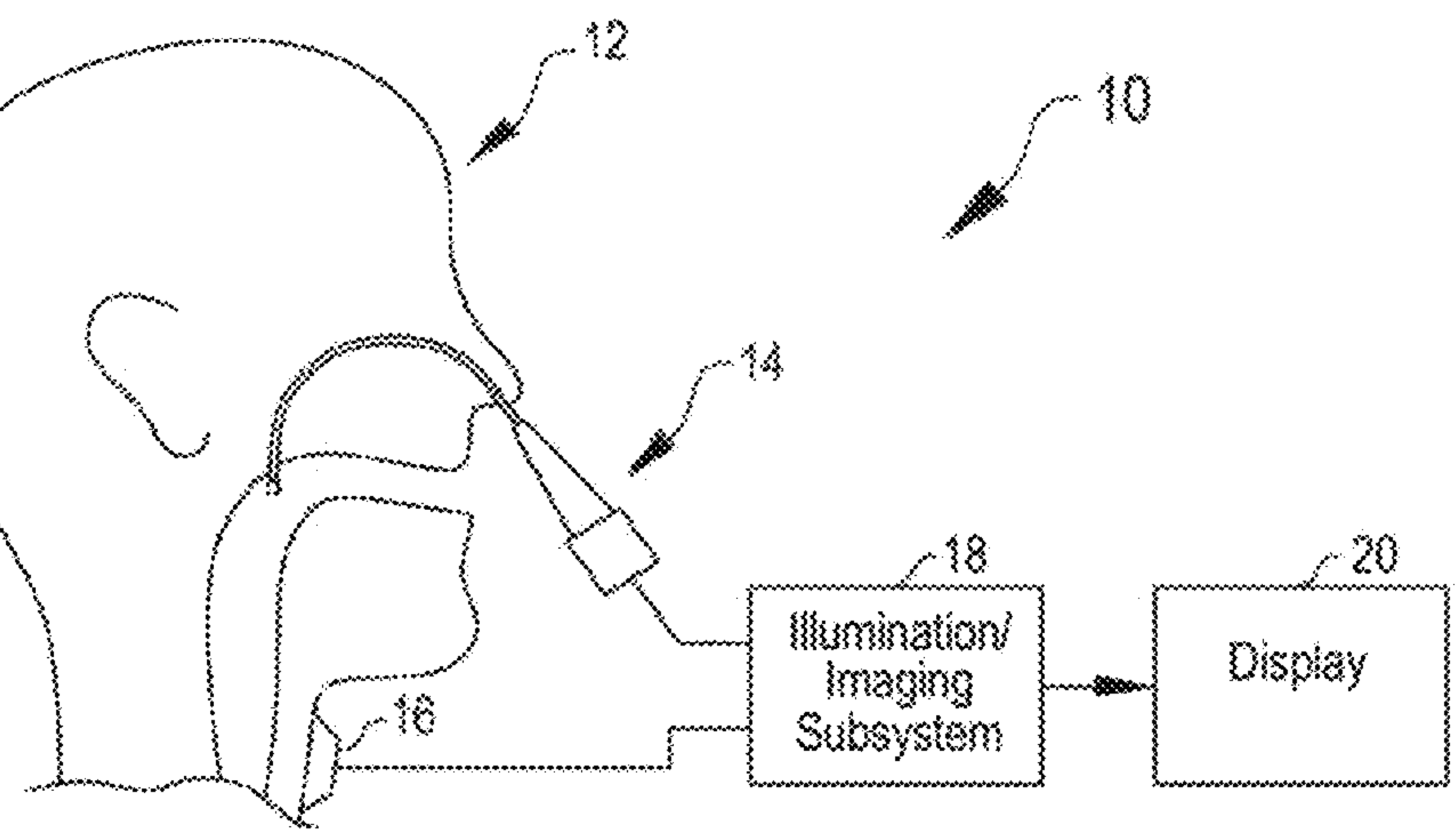

12
10
14
18
20
Illumination/
Imaging
Subsystem
Display
16

FIG. 2

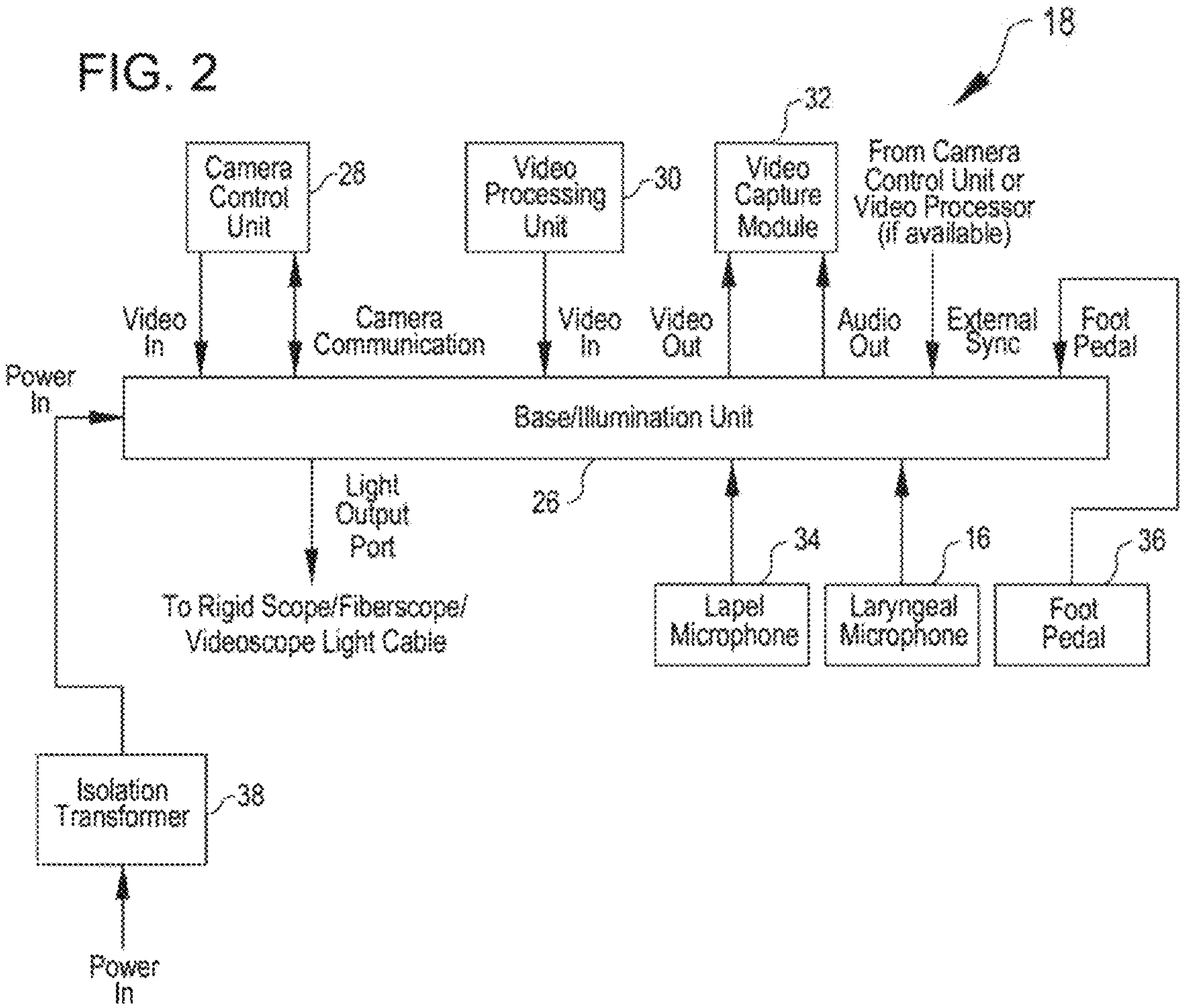

18
32
Camera
Control
Unit
28
Video
Processing
Unit
30
Video
Capture
Module
From Camera
Control Unit or
Video Processor
(if available)
Video
In
Camera
Communication
Video
In
Video
Out
Audio
Out
External
Sync
Foot
Pedal
Power
In
Base/Illumination Unit
Light
Output
Port
26
34
16
36
To Rigid Scope/Fiberscope/
Videoscope Light Cable
Lapel
Microphone
Laryngeal
Microphone
Foot
Pedal
Isolation
Transformer
38
Power
In

FIG. 3

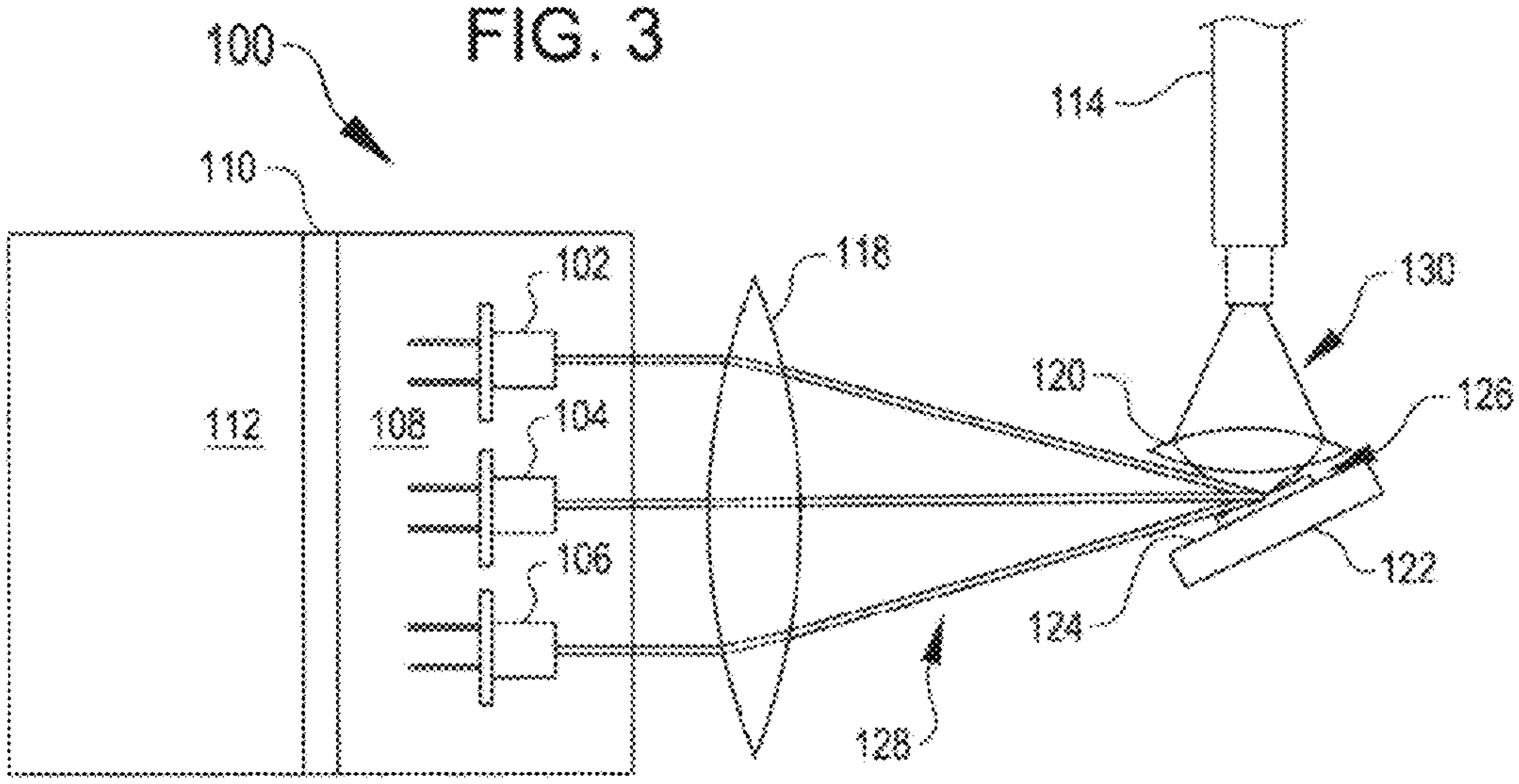

100
110
112
108
102
104
106
118
114
130
120
126
122
124
128

FIG. 4

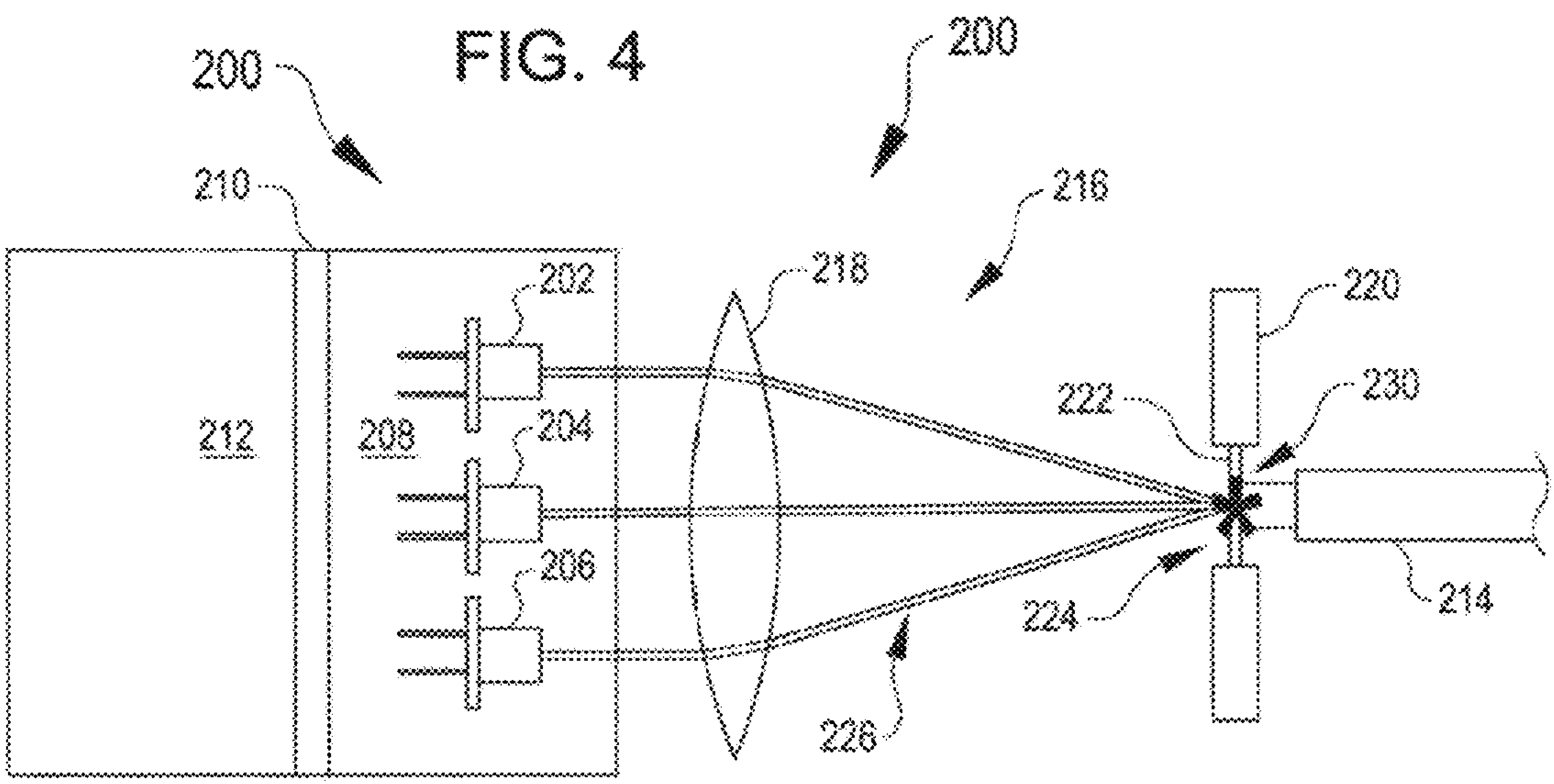

200
200
210
212
208
202
204
206
218
216
220
222
230
214
224
226

FIG. 5

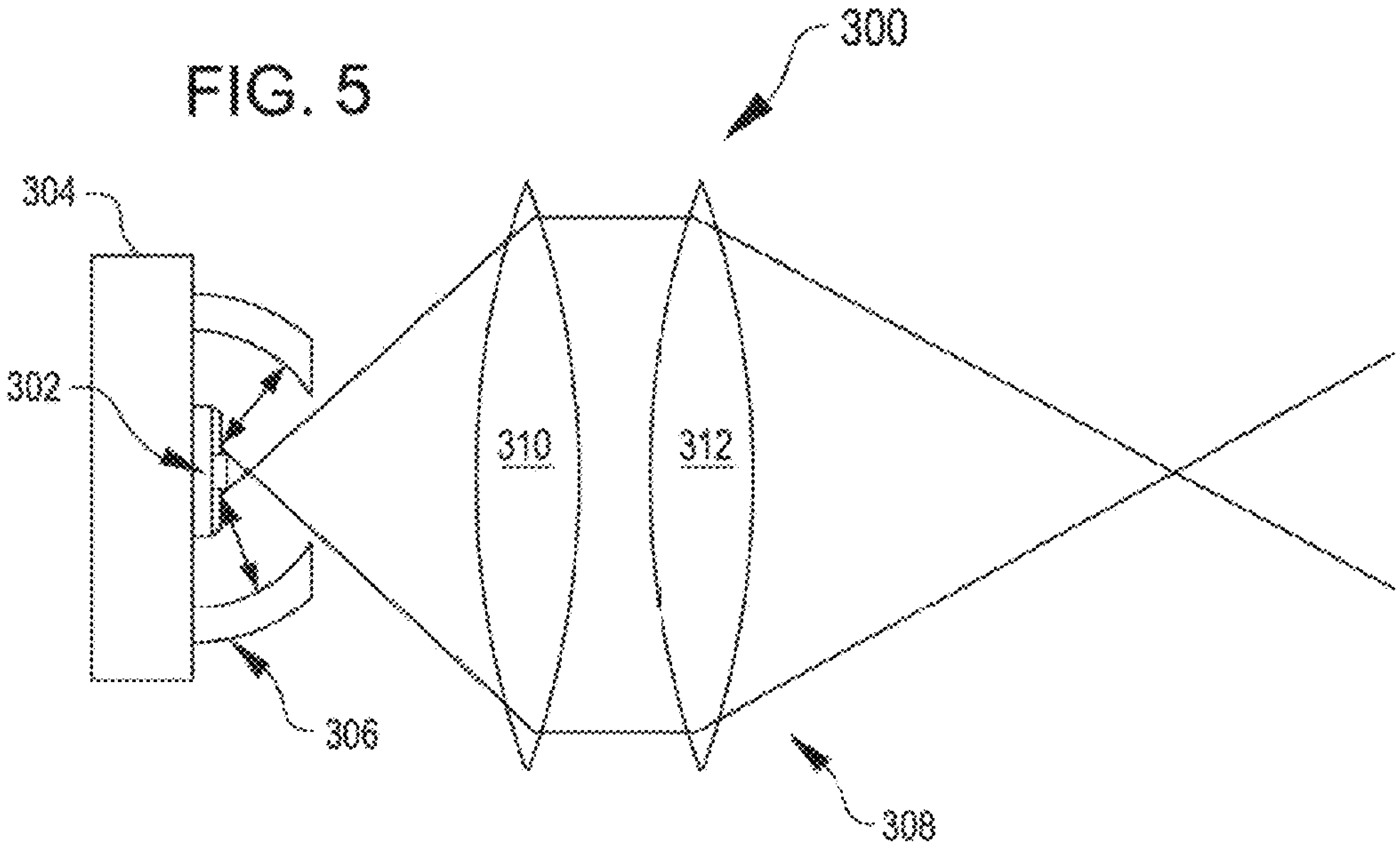


FIG. 6

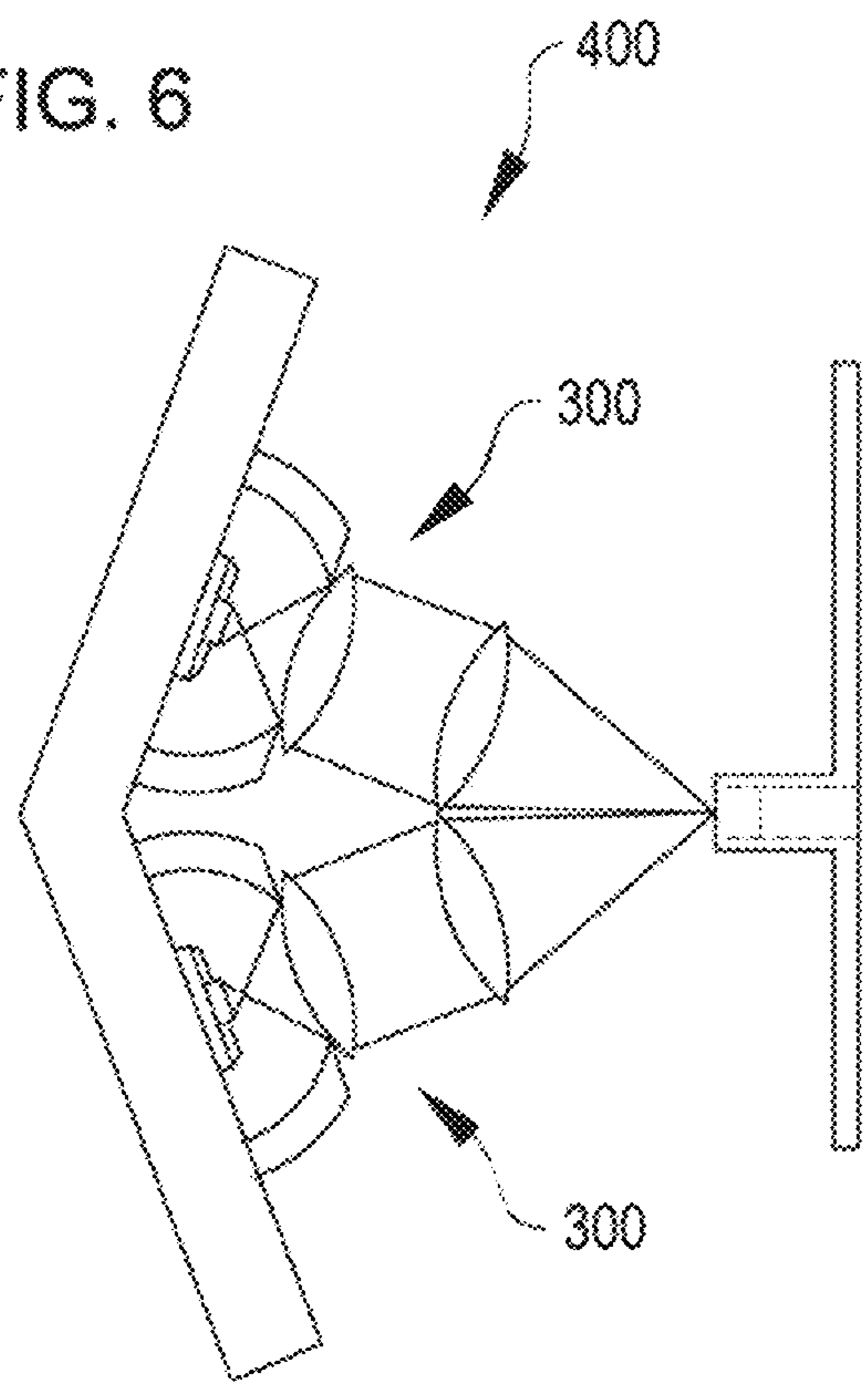


FIG. 7A

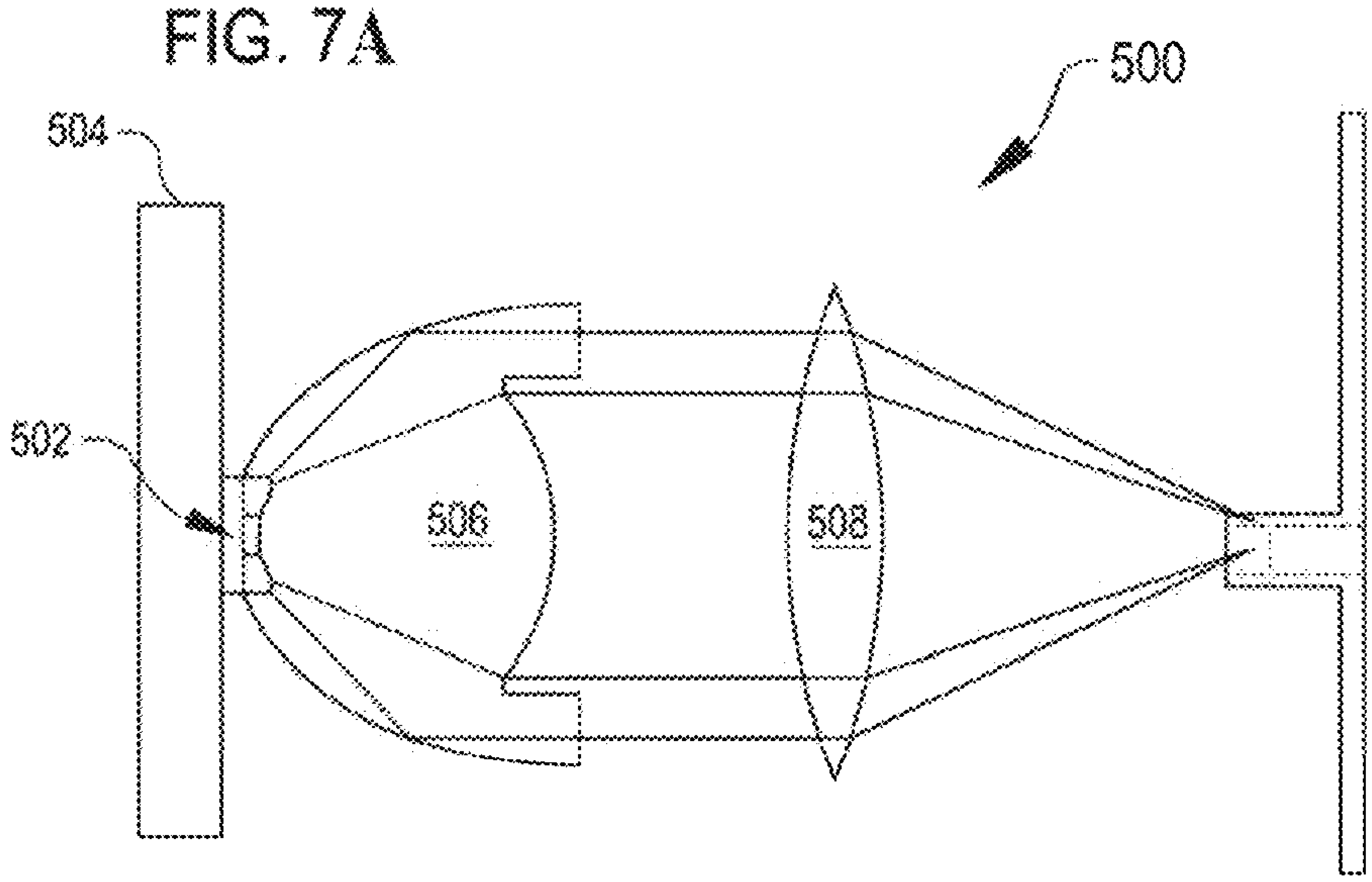

500
504
502
506
508

FIG. 7B

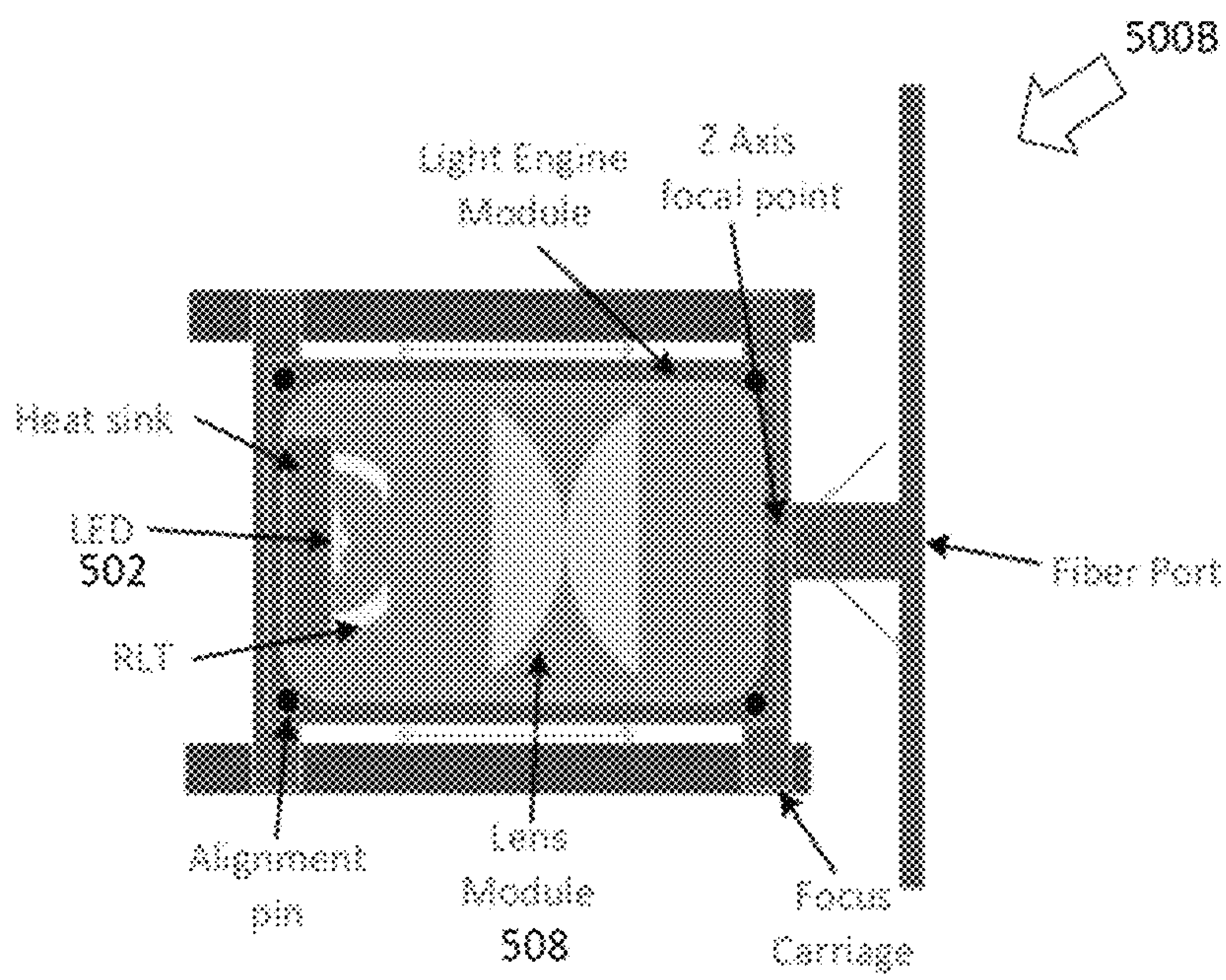

500B
Light Engine Module
Z Axis focal point
Heat sink
LED
502
RLT
Fiber Port
Alignment pin
Lens Module
508
Focus Carriage

FIG. 8

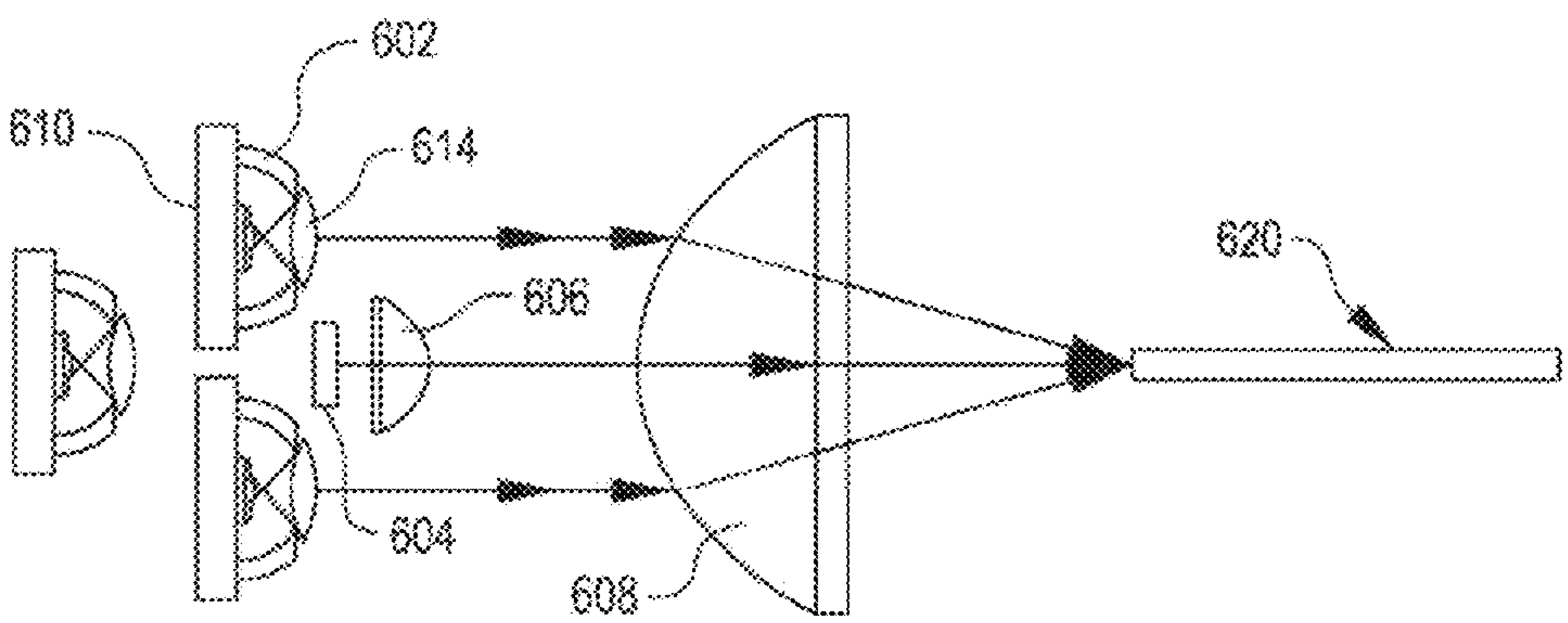


FIG. 9

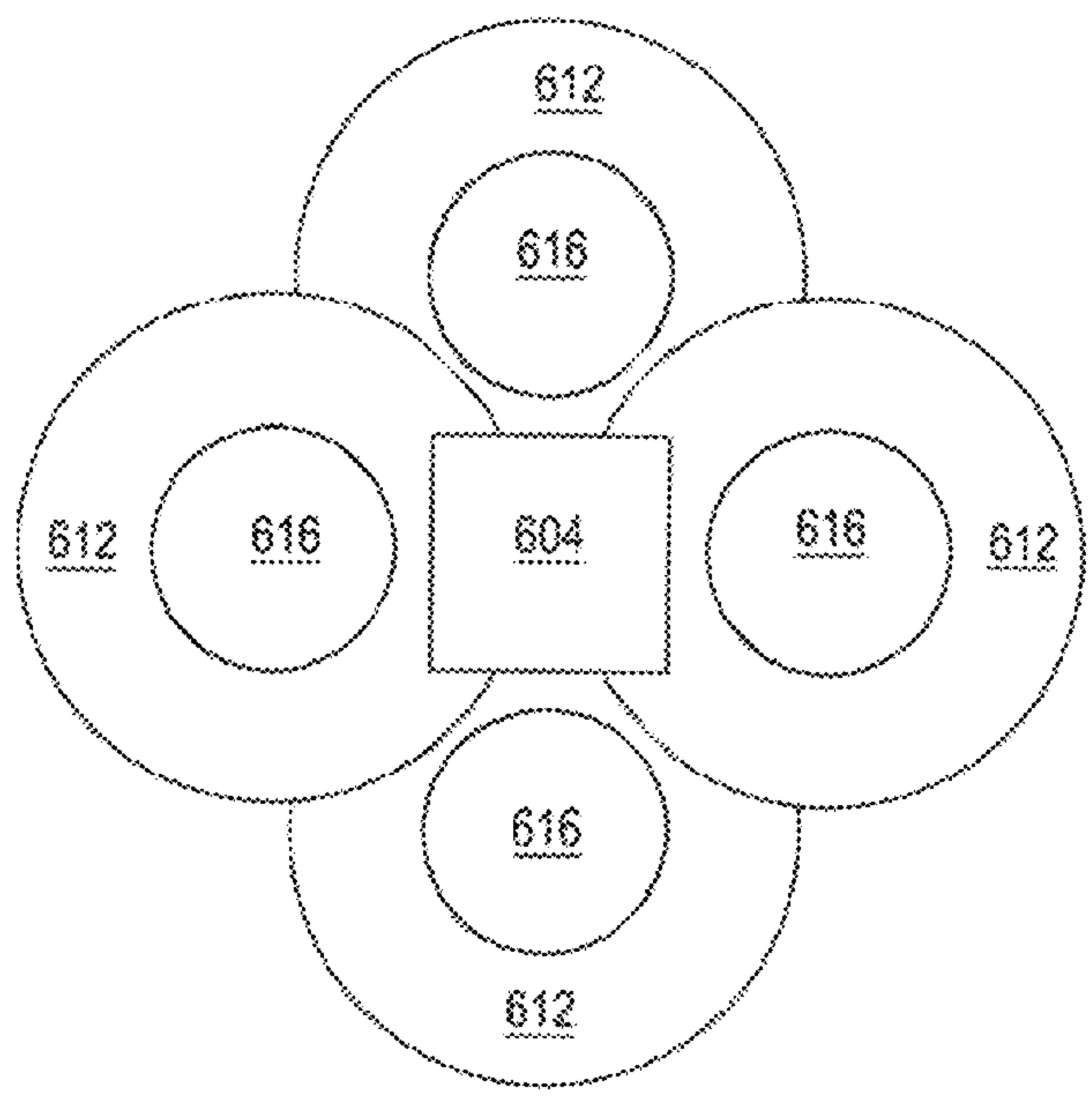


FIG. 10

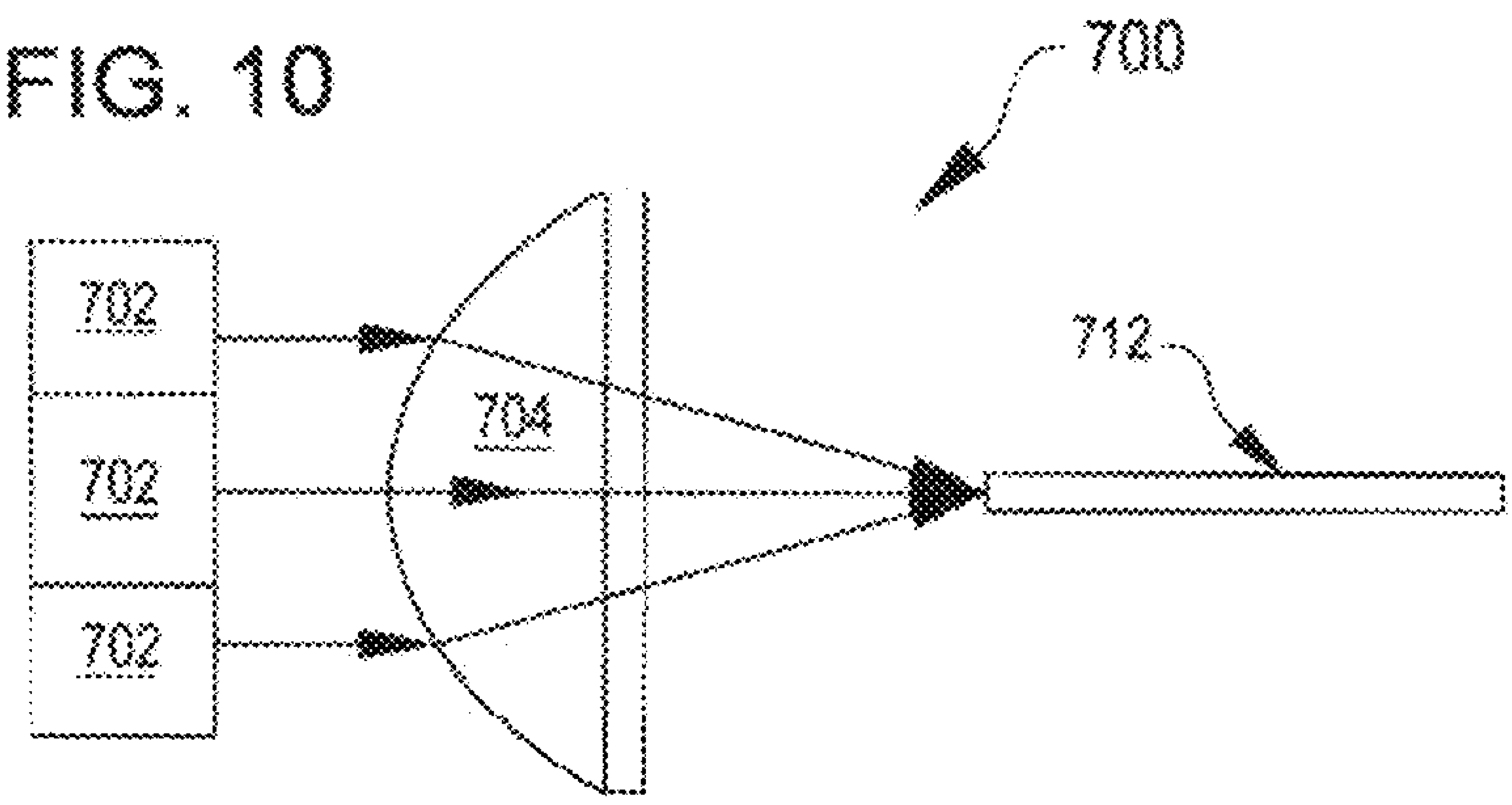


FIG. 11

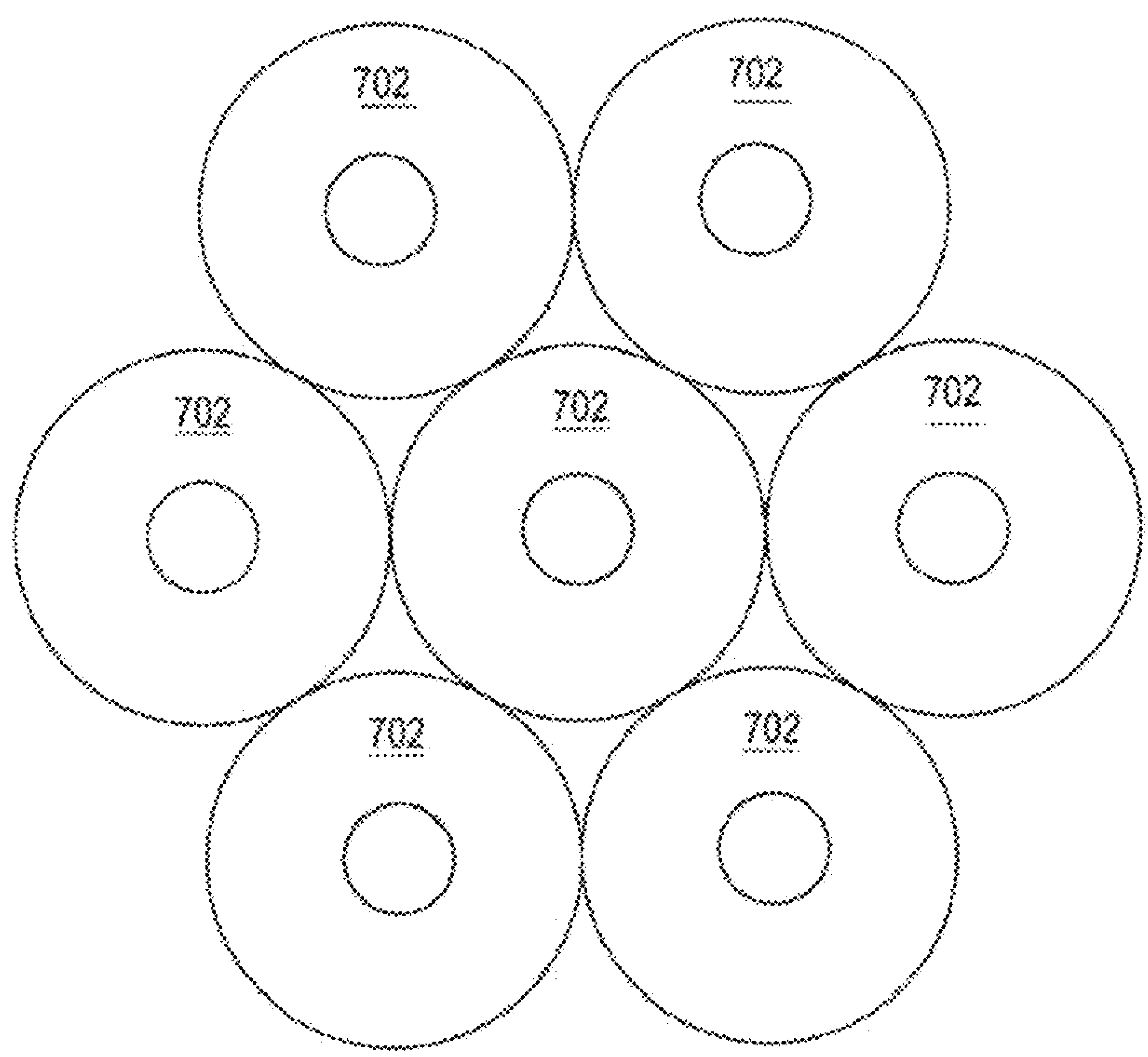


FIG. 12

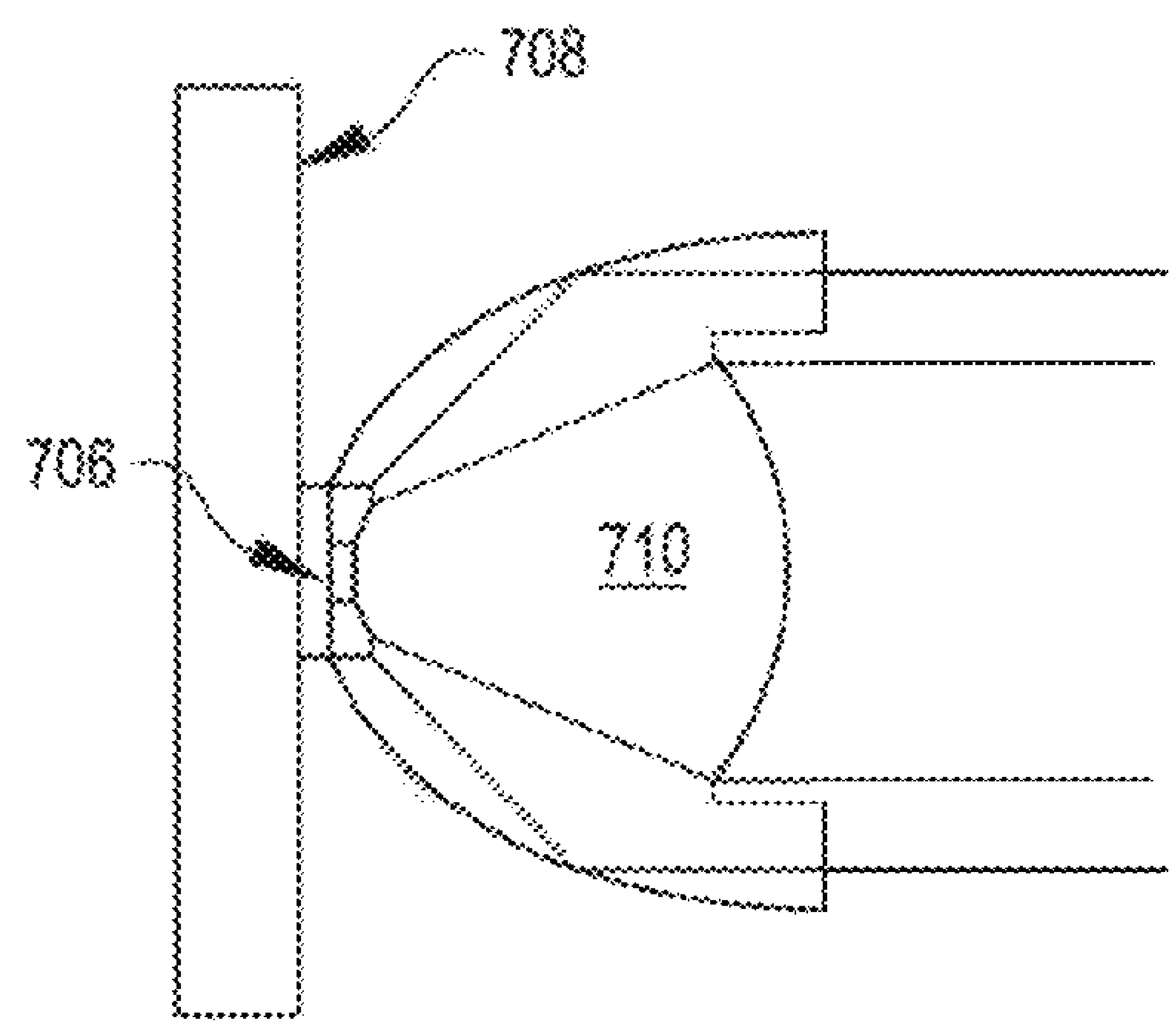
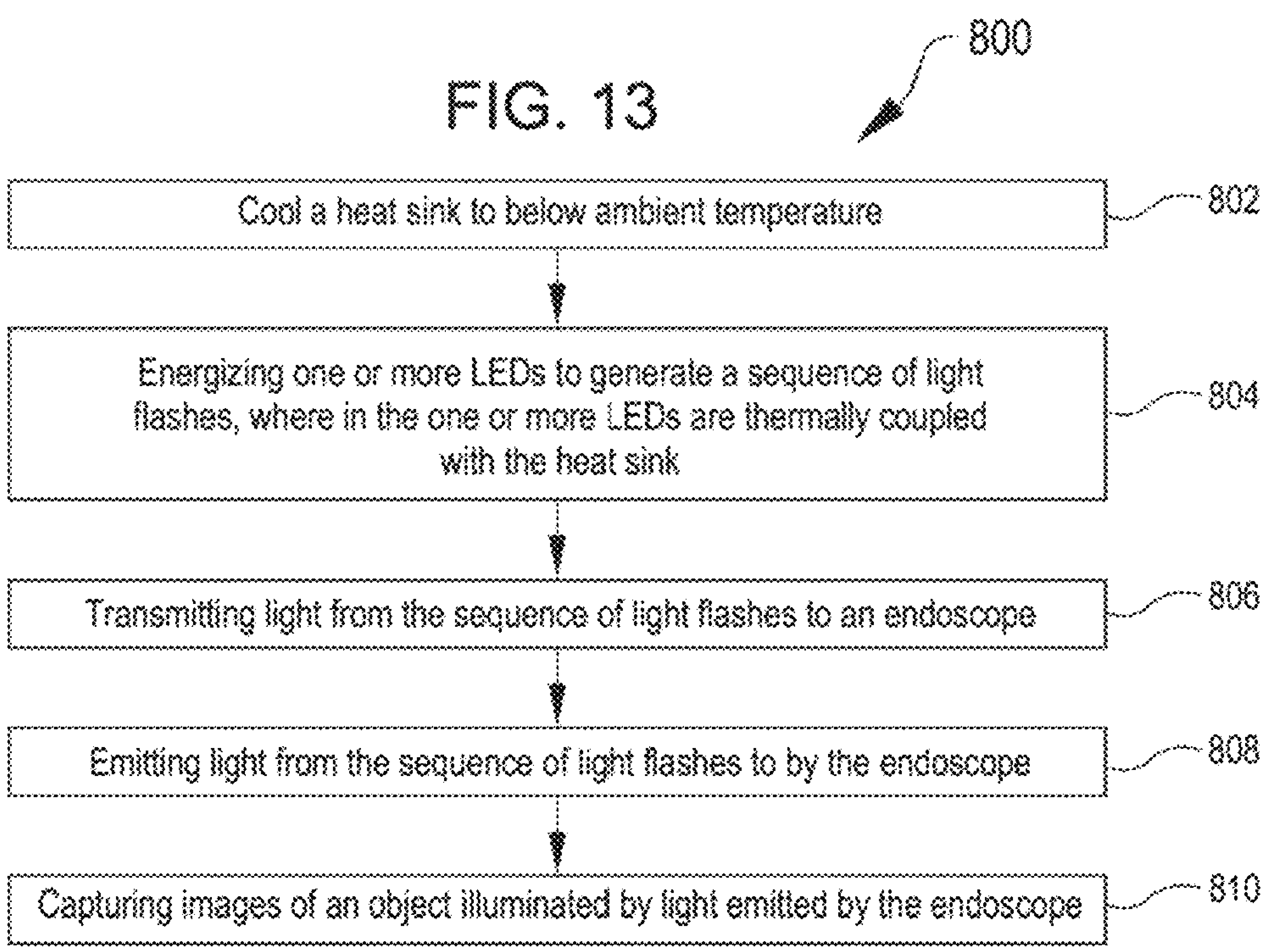

708
706
710

FIG. 13


800
Cool a heat sink to below ambient temperature
802
Energizing one or more LEDs to generate a sequence of light flashes, where in the one or more LEDs are thermally coupled with the heat sink
804
Transmitting light from the sequence of light flashes to an endoscope
806
Emitting light from the sequence of light flashes to by the endoscope
808
Capturing images of an object illuminated by light emitted by the endoscope
810

Patient Fundamental Phonation frequency 60 Hz - Pulse 300 us (1x300=300 us/frame)

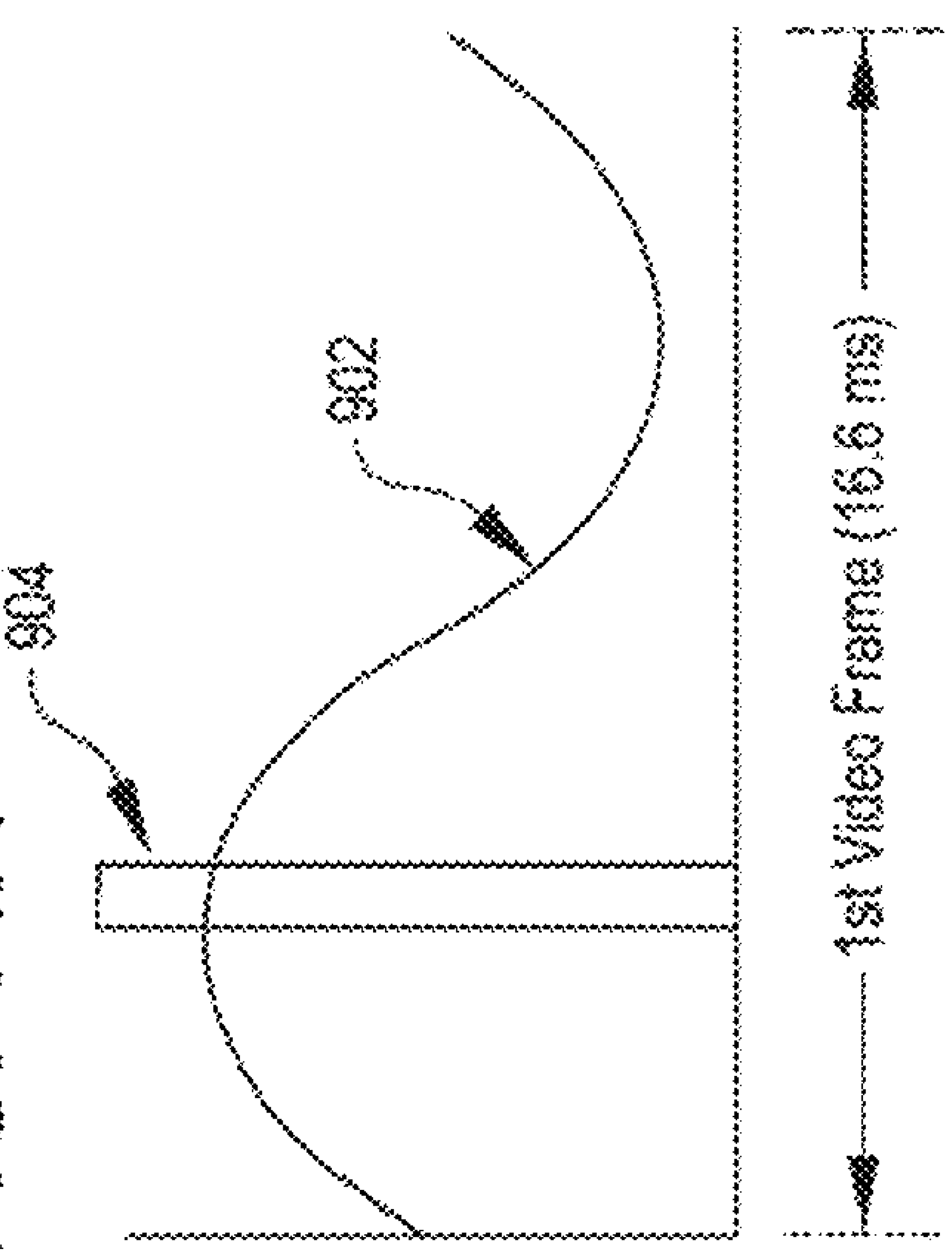


FIG. 14A

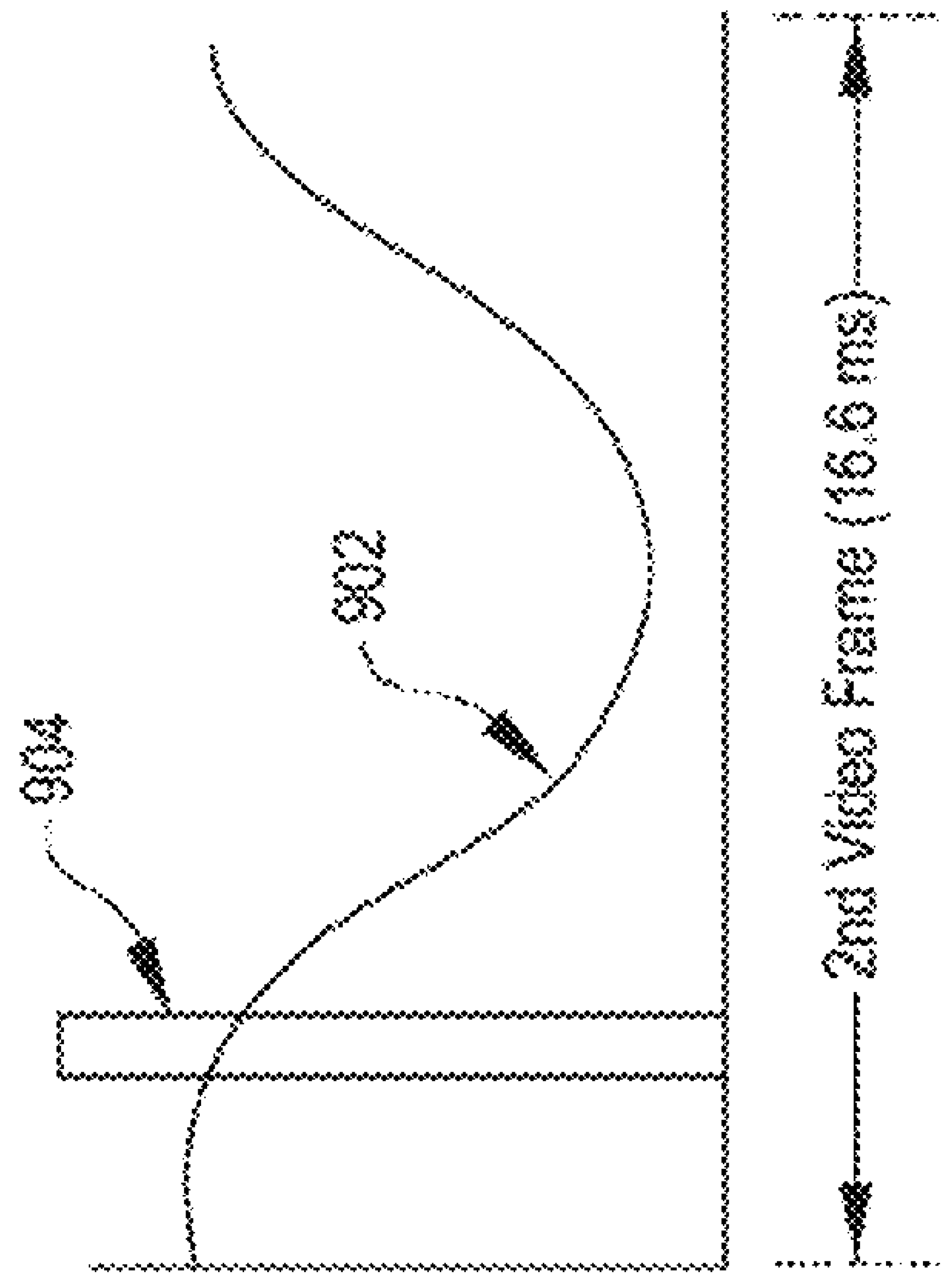


FIG. 14B

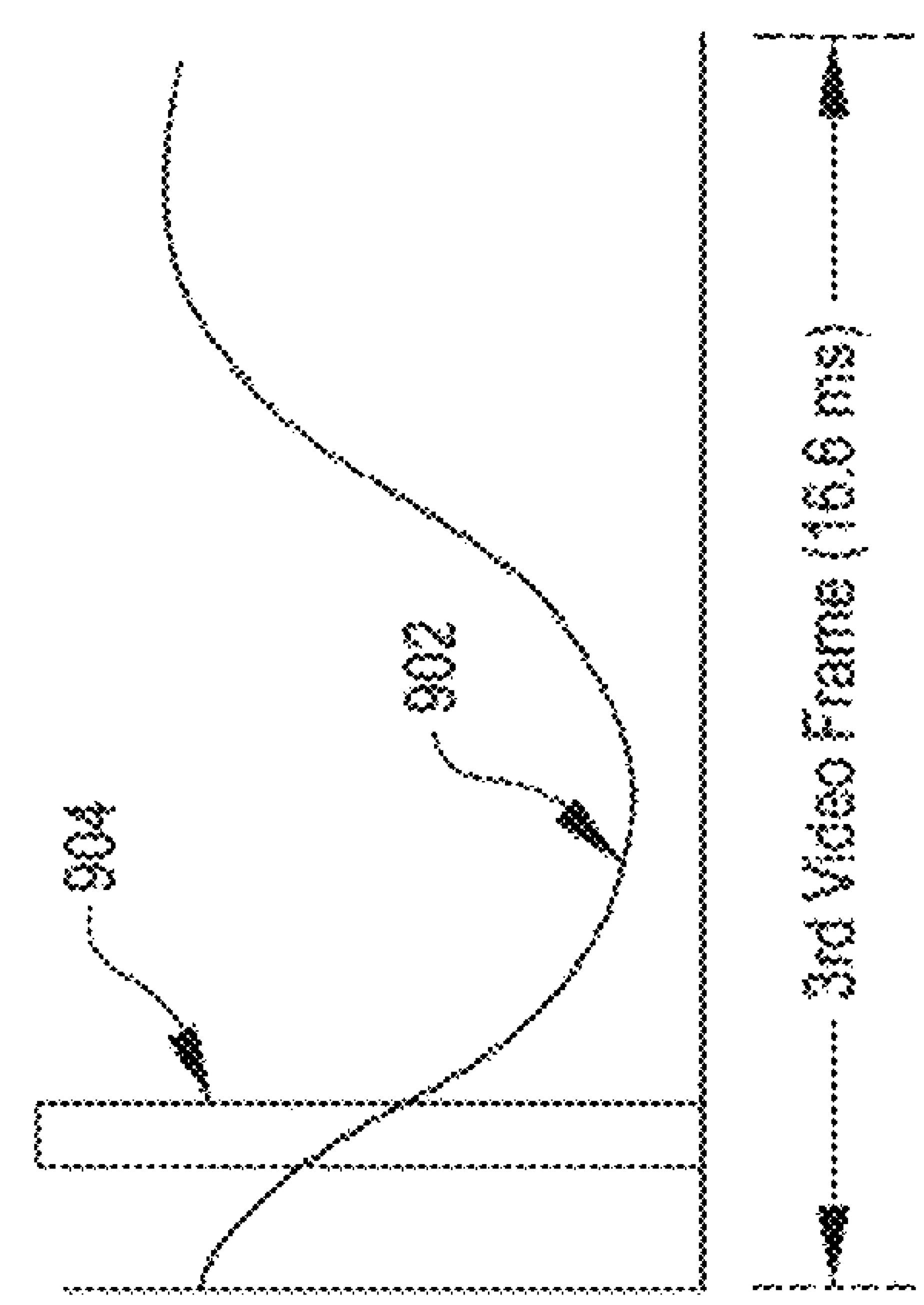


FIG. 14C

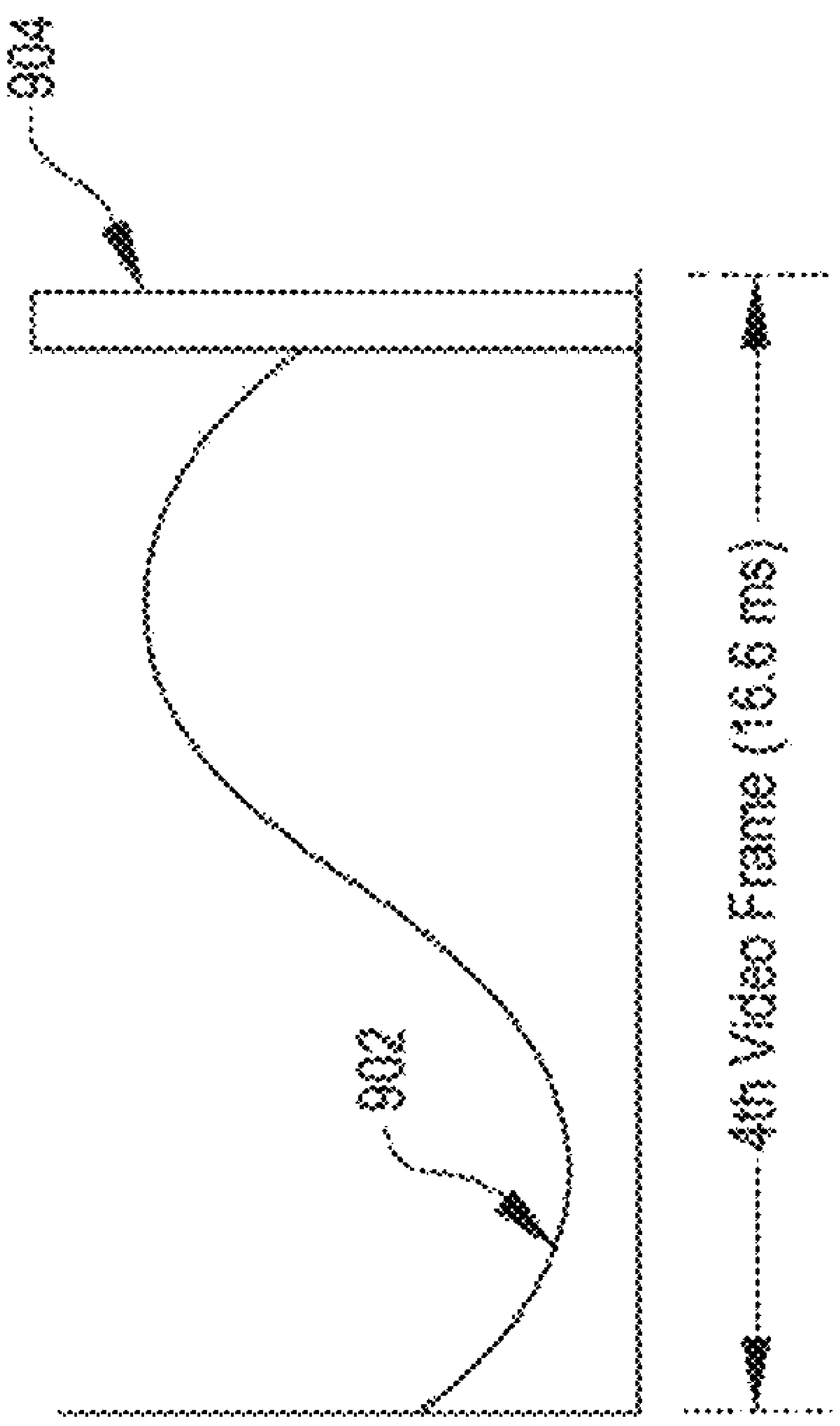


FIG. 14D

Patient Fundamental Phonation frequency 120 Hz - 2 Pulse 150 us (2x150us = 300 us/frame)

FIG. 15A

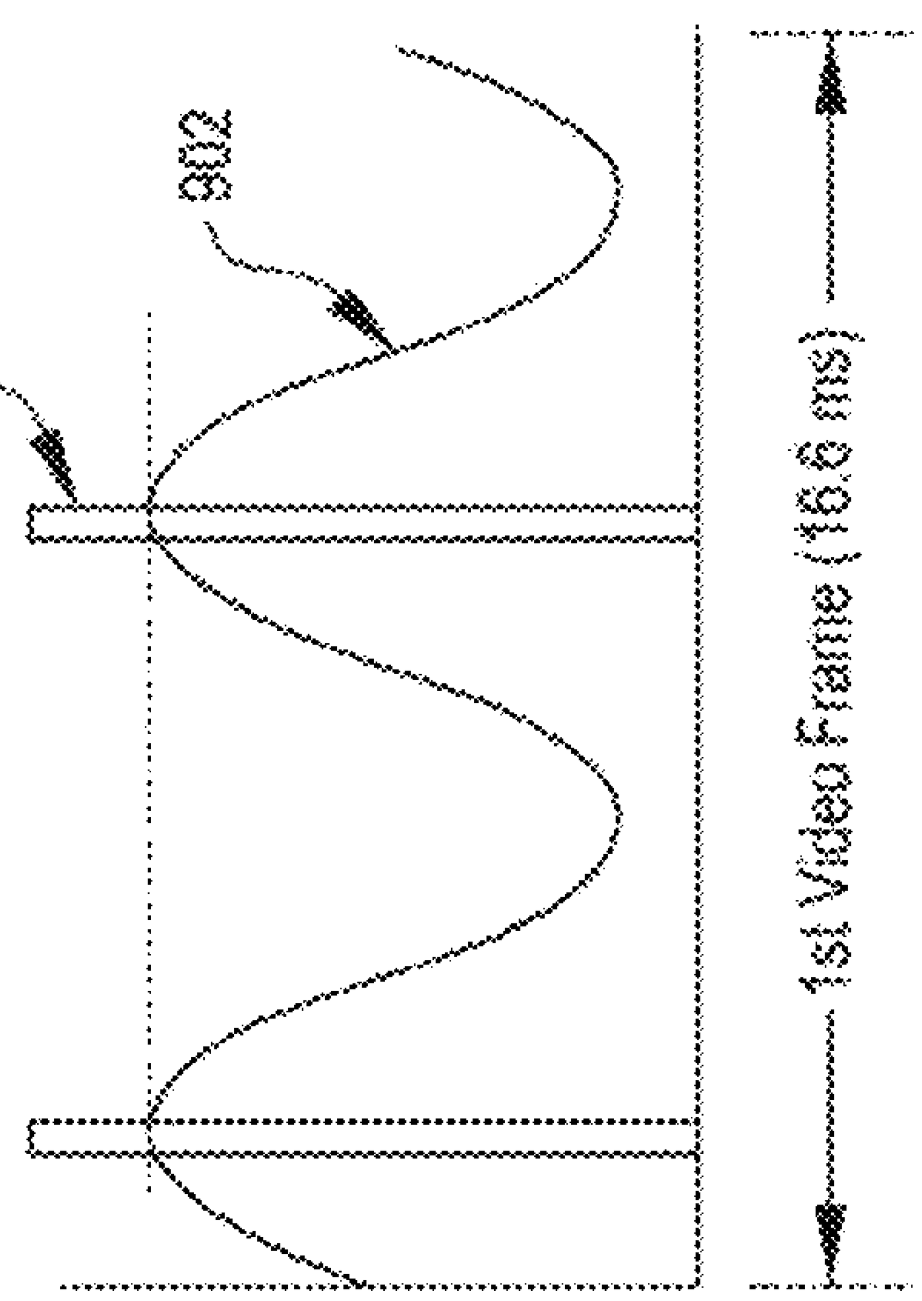


FIG. 15B

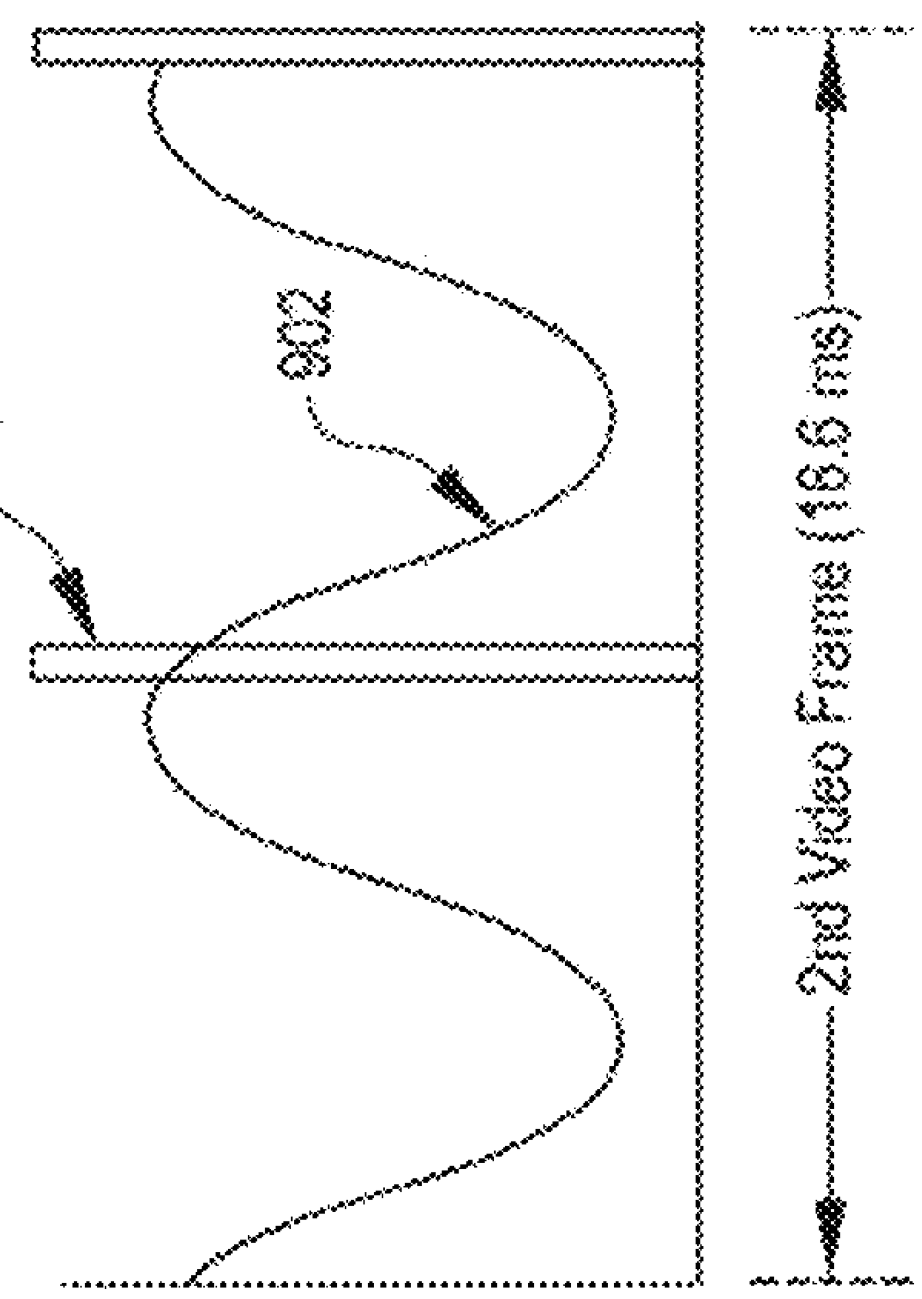


FIG. 15C

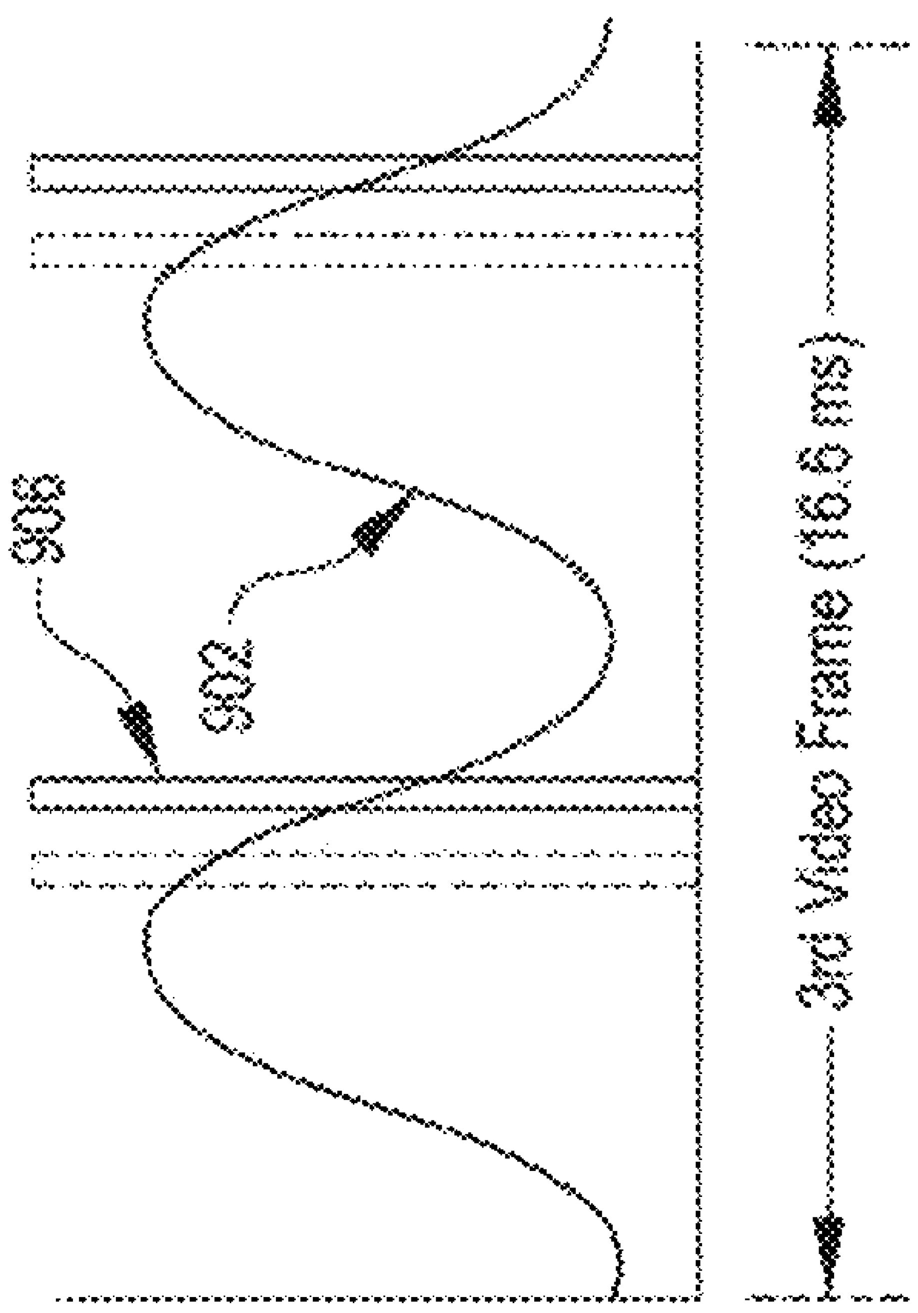
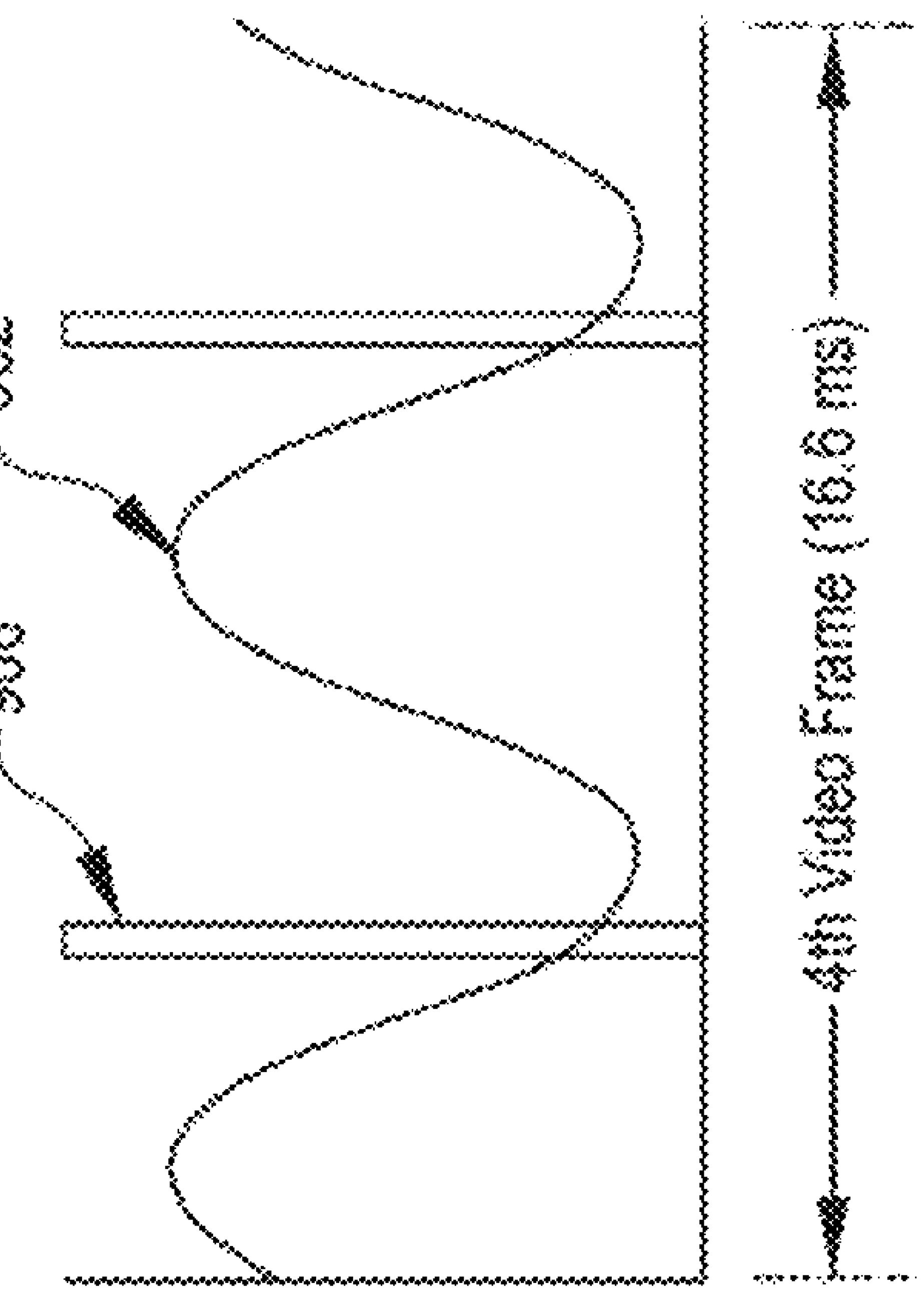


FIG. 15D



Patient Fundamental Phonation frequency 340 Hz - 3 Pulse 100 us (3x100us = 300 us/frame)

FIG. 16A

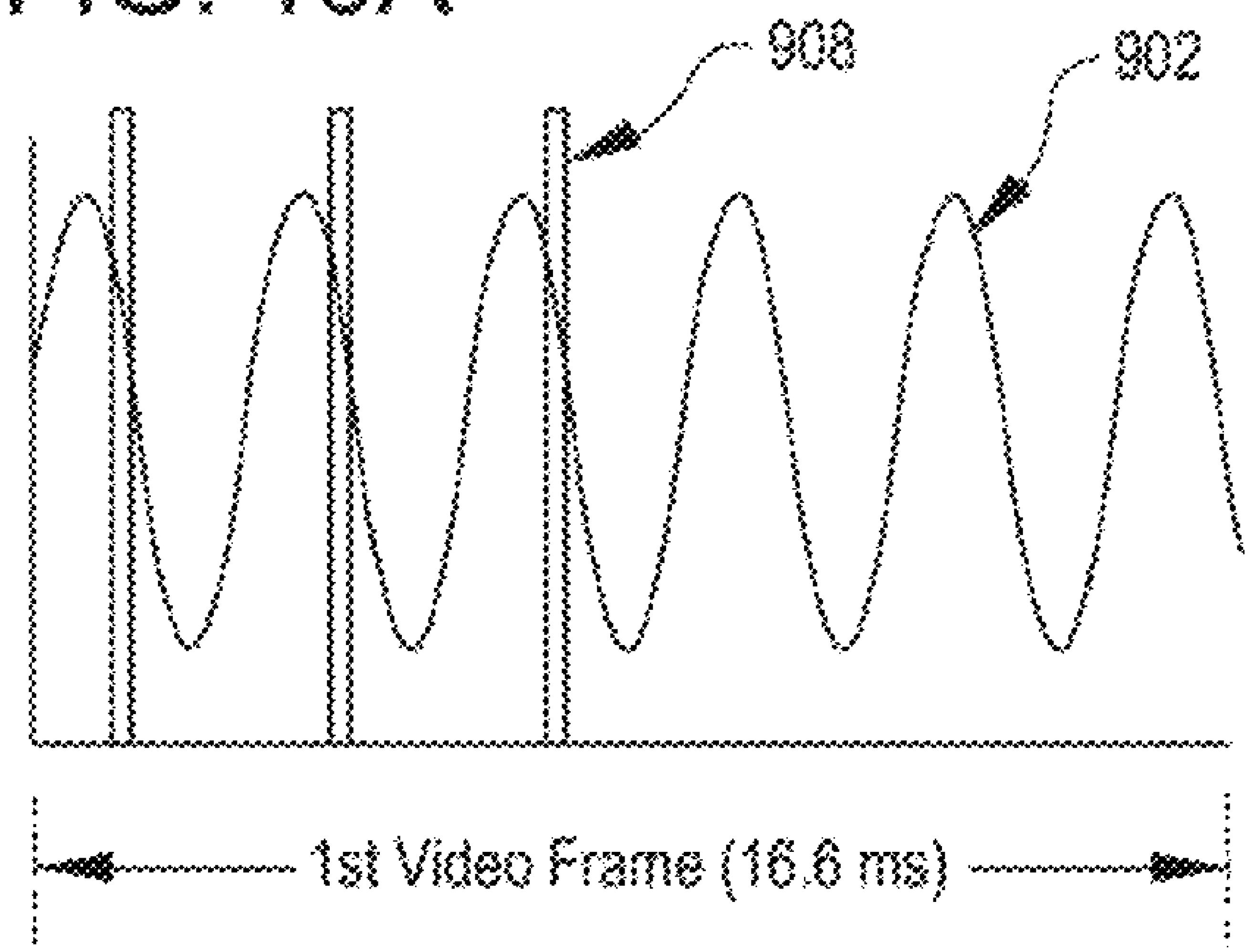


FIG. 16B

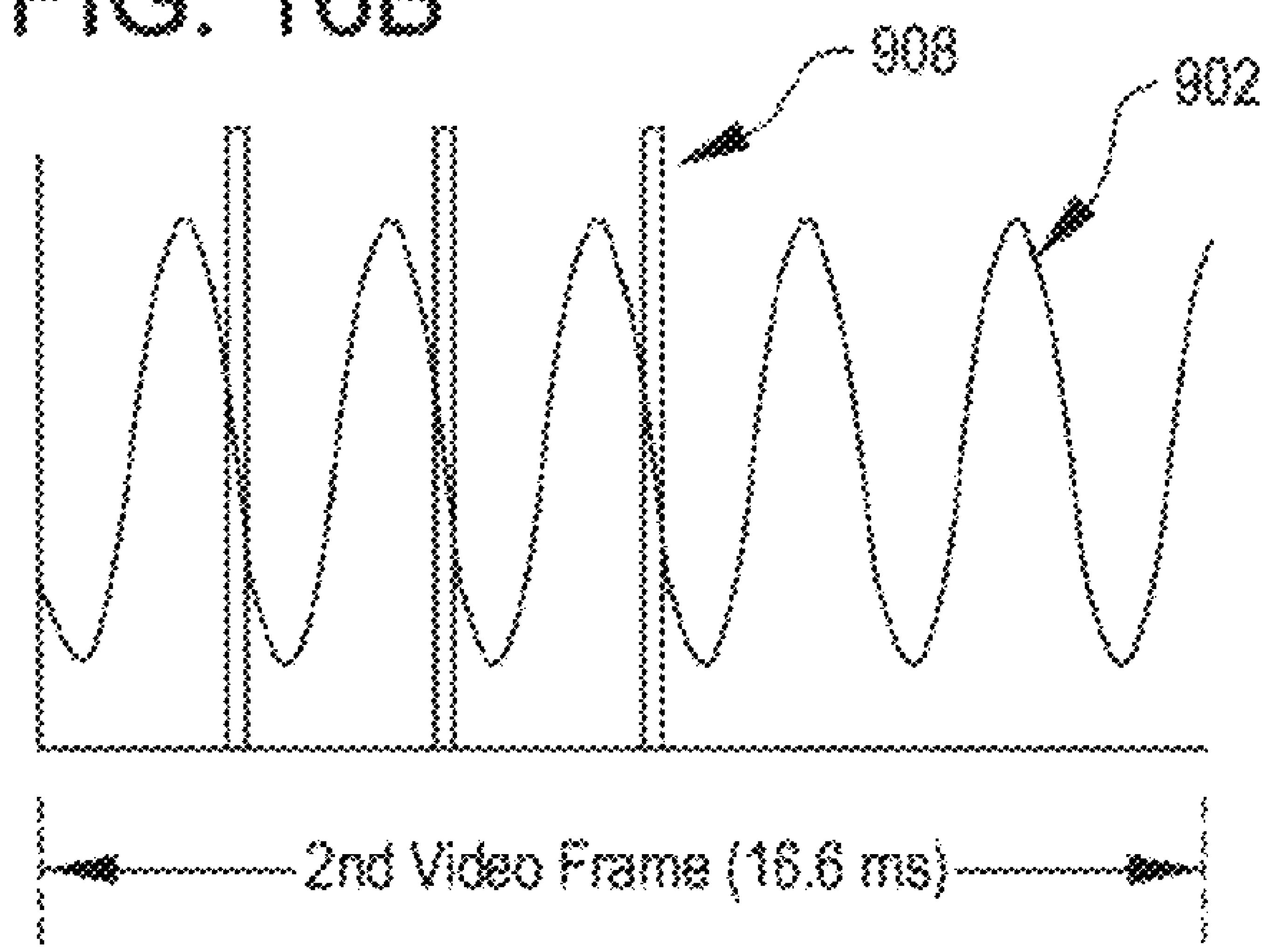


FIG. 16C

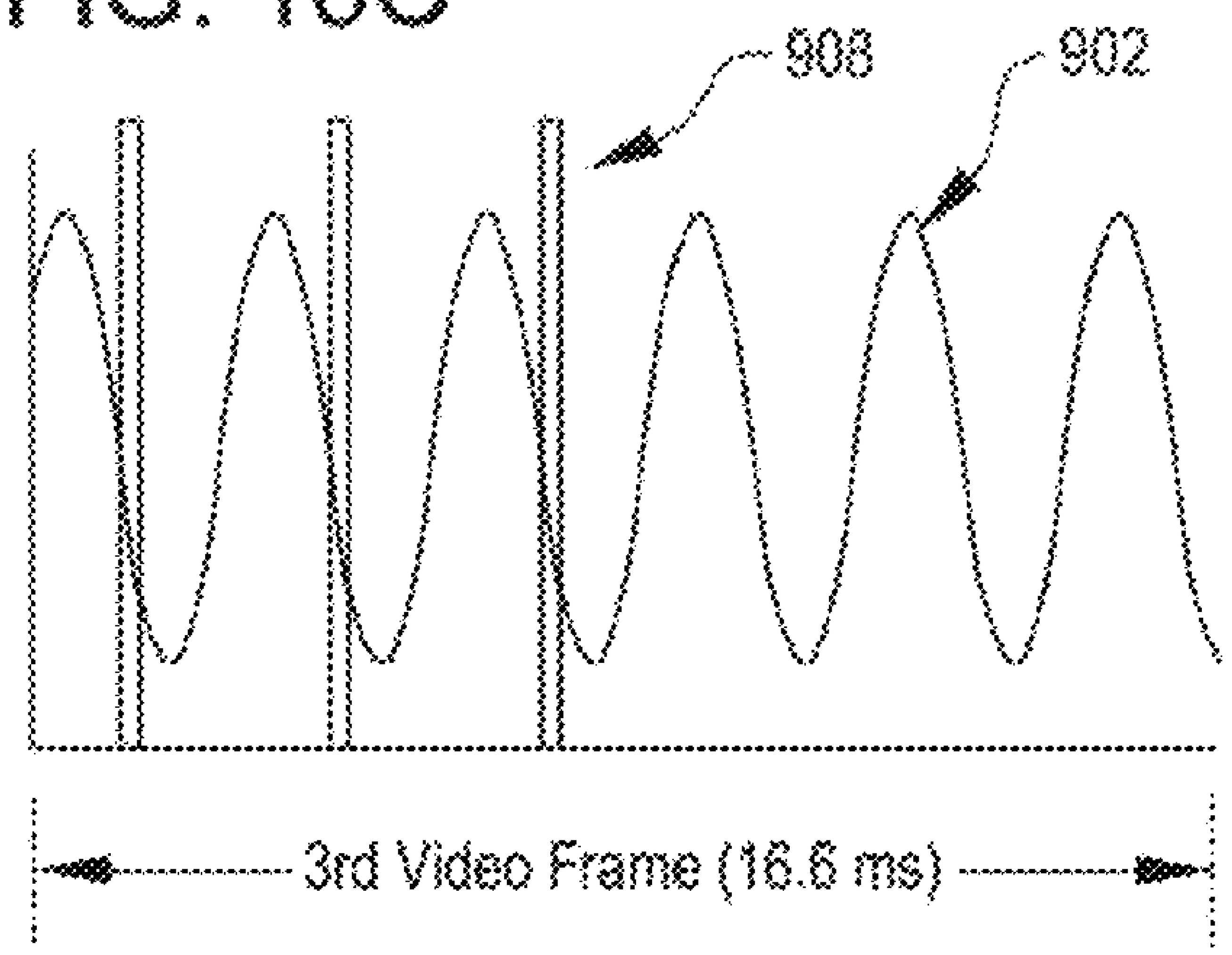


FIG. 16D

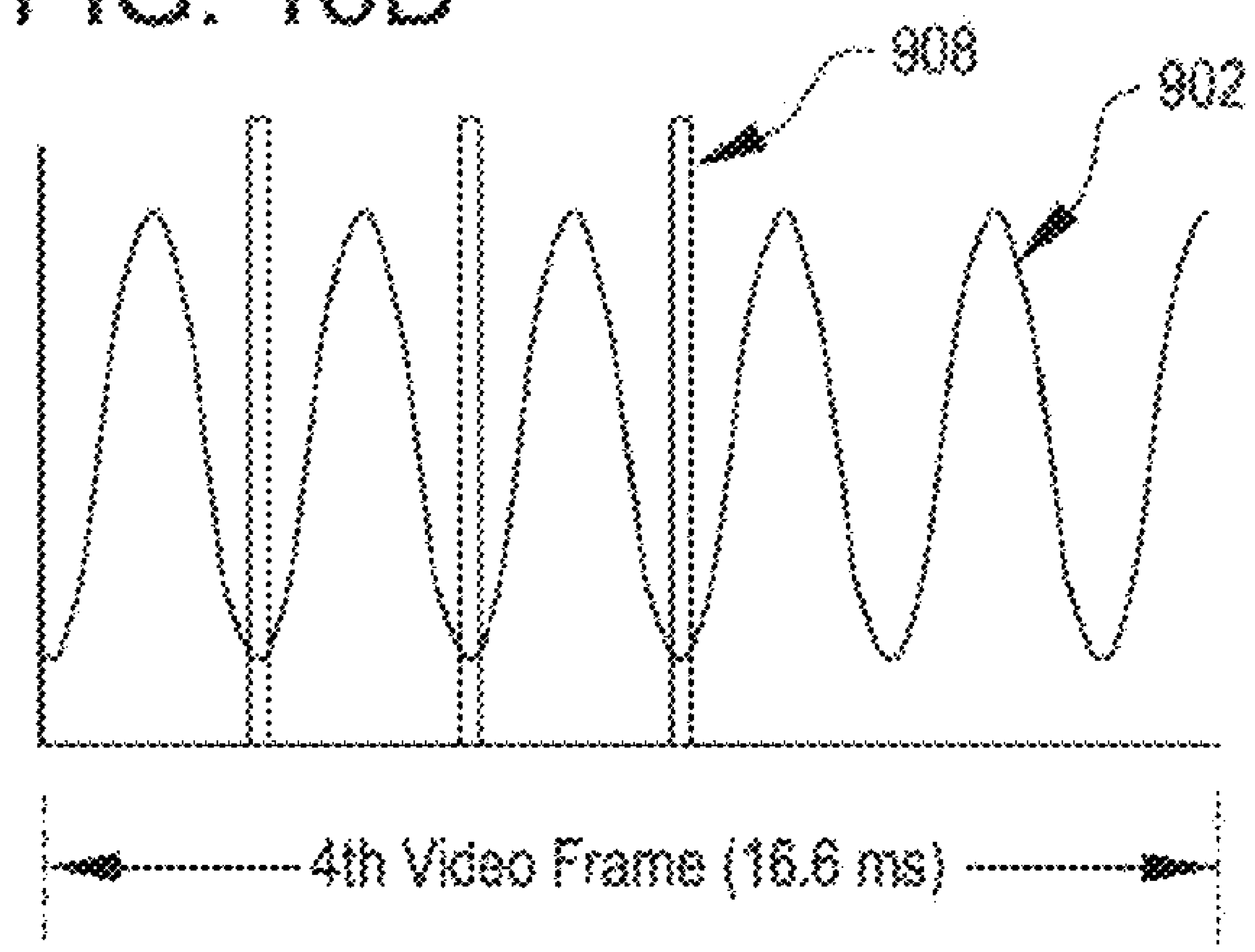
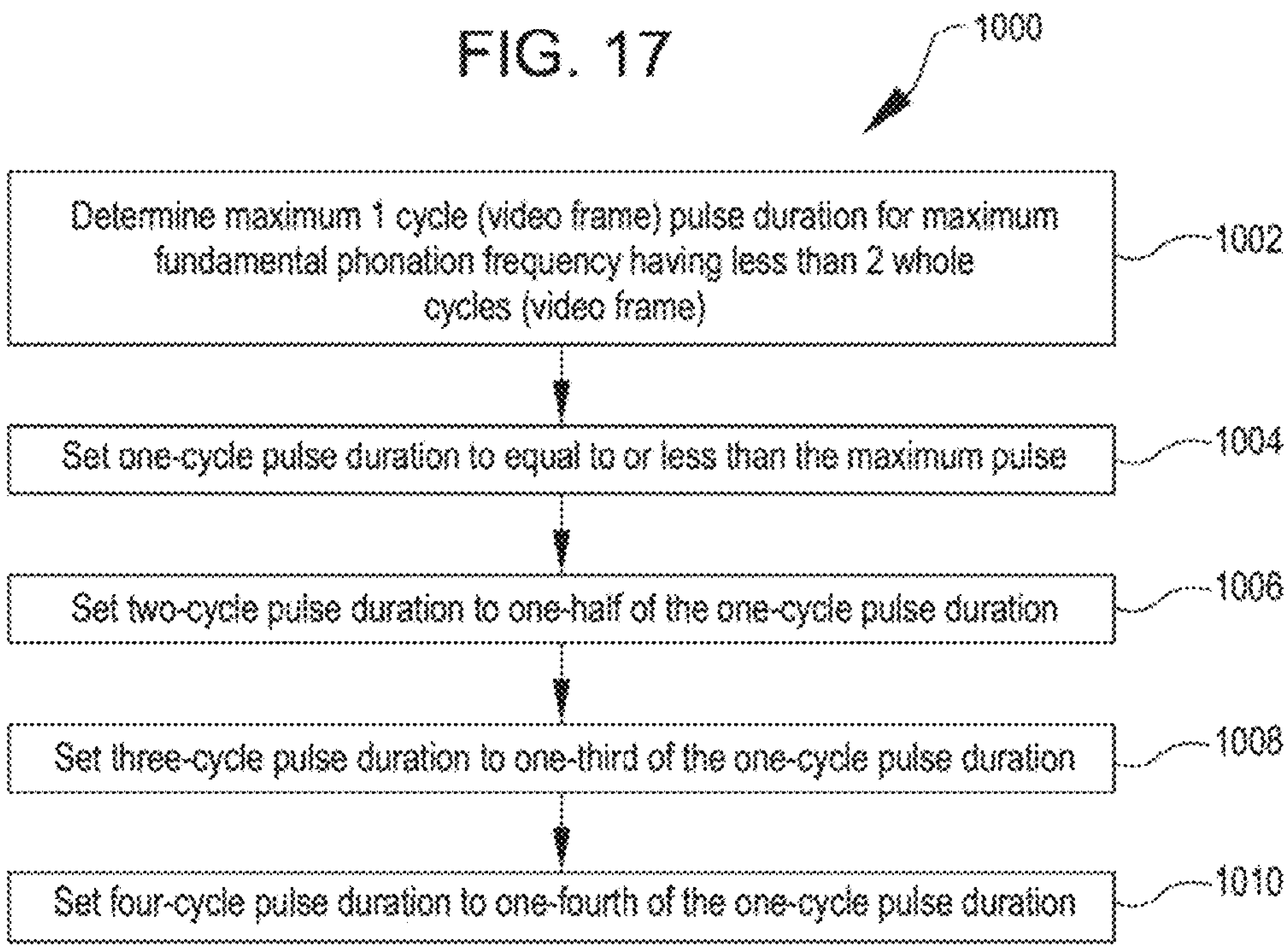


FIG. 17


1000
Determine maximum 1 cycle (video frame) pulse duration for maximum fundamental phonation frequency having less than 2 whole cycles (video frame)
1002
Set one-cycle pulse duration to equal to or less than the maximum pulse
1004
Set two-cycle pulse duration to one-half of the one-cycle pulse duration
1006
Set three-cycle pulse duration to one-third of the one-cycle pulse duration
1008
Set four-cycle pulse duration to one-fourth of the one-cycle pulse duration
1010

LARYNGEAL STROBOSCOPE UTILIZING SOLID STATE LIGHT SOURCES

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 63/171,666, filed Apr. 7, 2021. The contents of these earlier filed application is hereby incorporated by reference herein in its entirety.

BACKGROUND

A laryngeal stroboscope is used to generate sequence of images of a phonating larynx in such a way as to provide apparent slow motion video of the larynx for review by a treating professional. Many laryngeal stroboscopes generate stroboscopic illumination of a phonating larynx during imaging of the larynx by an electronic camera and ridged or flexible Laryngeal Scope. The pulse timing of the stroboscopic light can be controlled to synchronize each pulse with a derived fundamental frequency of the sound produced by the phonating larynx (e.g., obtained by a laryngeal microphone).

BRIEF SUMMARY

The following presents a simplified summary of some embodiments of the invention in order to provide a basic understanding of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some embodiments of the invention in a simplified form as a prelude to the more detailed description that is presented later.

Embodiments described herein are directed to stroboscopic endoscope systems and related methods. In many embodiments, one or more approaches are used to increase the amount of stroboscopic light generated by one or more LEDs and/or to increase the amount of stroboscopic light generated by one or more LEDs that is emitted by an endoscope to provide illumination of an object (e.g., a phonating larynx) for imaging of the object.

For example, in many embodiments, a stroboscopic endoscope system is configured to generate multiple light flashes during a video frame to repeatedly illuminate matching segments of vocal cord displacement cycles that occur during the video frame so as to increase the total amount of light used to illuminate the vocal cord during the video frame. Additionally, image blurring can be inhibited or avoided by keeping the duration of the light flashes short enough to avoid image blurring and illuminating the same segment of the respective vocal cord segments with each of the light flashes.

In many embodiments, a stroboscopic endoscope system includes an endoscope, an imaging device, and one or more LEDs that are intermittently energized to generate a sequence of light flashes emitted by the endoscope to illuminate an object (e.g., a phonating larynx) for imaging by imaging device. In many embodiments, the one or more LEDs are thermally coupled with a heat sink that is precooled prior to being intermittently energized. By precooling the heat sink, the one or more LEDs can be energized at a higher power level (which produces greater amount of light) without detrimental impact on the resulting operational life of the one or more LEDs due to the resulting increased cooling of the one or more LEDs.

In many embodiments, a stroboscopic endoscope system includes an endoscope, an imaging device, one or more LEDs, and a light redirecting assembly. The one or more LEDs are intermittently energized to generate a sequence of light flashes emitted by the endoscope to illuminate an object (e.g., a phonating larynx) for imaging by imaging device. In many embodiments, the light redirecting assembly is configured to increase the amount of light that is generated by the one or more LEDs that is emitted by the endoscope to provide illumination of an object (e.g., a phonating larynx) for imaging of the object. For example, in some embodiments, the light redirecting assembly comprises one or more hemispherical reflectors configured to increase the amount of light that is generated by the one or more LEDs that is emitted by the endoscope. In some embodiments, the light redirecting assembly comprises one or more total internal reflectors configured to increase the amount of light that is generated by the one or more LEDs that is emitted by the endoscope. By increasing the amount of the light generated by the one or more LEDs that is emitted by the endoscope, the one or more LEDs can have a reduced light output, thereby reducing cost and power consumption.

Thus, in one aspect, a stroboscopic endoscope system includes an endoscope, a video device, a first light emitting diode (LED), a light transmission assembly, a microphone, and a controller. The endoscope includes a light guide. The video device is configured for imaging vocal chords of a patient that are illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the first light source to the light guide. The microphone is configured to generate a microphone output signal in response to vocalization of the patient. The controller is operative coupled with the first light source, the video device, and the microphone. The controller is configured to process the microphone output signal to track a fundamental phonation frequency of the patient. The controller is configured to energize the first light source to generate a sequence of two or more light flashes in synchronization with the fundamental phonation frequency during a first video frame of the video device during which the vocal chords complete at least two complete displacement cycles so that the sequence of two or more light flashes illuminate matching segments of the at least two complete displacement cycles. The controller can be further configured to energize the first light source to generate a single light flash in synchronization with the fundamental phonation frequency during a second video frame of the video device during which the vocal chords complete less than two complete displacement cycles so that the single light flash illuminates a selected segment of one displacement cycle of the less than two complete displacement cycles. In many embodiments, the single light flash has a single light flash duration. The sequence of two or more light flashes can consist of two light flashes. Each of the two light flashes can have any suitable duration, for example, a duration equal to one-half of the single light flash duration.

The controller can be further configured to energize the first light source to generate a sequence of three or more light flashes in synchronization with the fundamental phonation frequency during a third video frame of the video device during which the vocal chords complete at least three complete displacement cycles so that the sequence of three or more light flashes illuminate matching segments of the at least three complete displacement cycles. The sequence of three or more light flashes can consist of three light flashes.

Each of the three light flashes can have any suitable duration, for example, a duration equal to one-third of the single light flash duration.

The controller can be further configured to energize the first light source to generate a sequence of four or more light flashes in synchronization with the fundamental phonation frequency during a fourth video frame of the video device during which the vocal chords complete at least four complete displacement cycles so that the sequence of four or more light flashes illuminate matching segments of the at least four complete displacement cycles. The sequence of four or more light flashes can consist of four light flashes. Each of the four light flashes can have any suitable duration, for example, a duration equal to one-fourth of the single light flash duration.

The stroboscopic endoscope system can further include a heat sink and a thermoelectric cooler. The heat sink can be coupled with the first light source to transfer heat generated by the first light source to the heat sink. The thermoelectric cooler can be coupled with the heat sink and operable to remove heat from the heat sink. The controller can be operative coupled with the thermoelectric cooler and configured to operate the thermoelectric cooler to cool the heat sink to below an ambient temperature of air surrounding the heat sink prior to energizing the first light source to generate the sequence of light flashes. The heat sink can be cooled to any suitable temperature below ambient temperature, for example, at least 5 degrees Celsius below the ambient temperature, or at least 10 degrees Celsius below the ambient temperature.

The stroboscopic endoscope system can further include a hemispherical reflector configured to redirect light generated by the first light source into the light transmission assembly for transmission to the light guide. The stroboscopic endoscope system can further include an image processor configured to perform color balancing of images captured via the endoscope to compensate for a first shift in spectrum induced by the hemispherical reflector. The first light source can include a phosphor coating configured to emit white light.

The stroboscopic endoscope system can further include a total internal reflector configured to redirect light generated by the first light source into the light transmission assembly via total internal reflection for transmission to the endoscope for emission by the endoscope. The first light source can be configured to generate monochromatic light. The light transmission assembly can include ceramic phosphors. In some embodiments, the sequence of light flashes excite the ceramic phosphors so as to generate a sequence of white light flashes that are transmitted to the light guide. In some embodiments, the ceramic phosphors are excited in a reflective mode. In some embodiments, the ceramic phosphors are excited in a transmissive mode.

In another aspect, a stroboscopic endoscope system includes an endoscope, a video device, a first light source, a second light source, a light transmission assembly, and a controller. The endoscope includes a light guide. The video device is configured for imaging vocal chords of a patient that are illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the first light source and the second light source to the light guide. The light transmission assembly includes a converging lens configured to converge each of light generated by the first light source and light generated by the second light source into the light guide. The controller is operative coupled with the first light source and configured to energize the first light source to generate a sequence of light flashes used to illuminate the vocal chords of the patient.

The stroboscopic endoscope system can include a heat sink and a thermoelectric cooler. The heat sink can be coupled with the first light source and the second light source to transfer heat generated by the first light source and the second light source to the heat sink. The thermoelectric cooler can be coupled with the heat sink and operable to remove heat from the heat sink. The controller can be operative coupled with the thermoelectric cooler and configured to operate the thermoelectric cooler to cool the heat sink to below an ambient temperature of air surrounding the heat sink prior to energizing the first light source and the second light source to generate the sequence of light flashes. The heat sink can be cooled to any suitable temperature below the ambient temperature. For example, the heat sink can cooled to at least 5 degrees Celsius below the ambient temperature, or to at least 10 degrees Celsius below the ambient temperature.

The stroboscopic endoscope system can include a first hemispherical reflector and a second hemispherical reflector. The first hemispherical reflector can be configured to redirect light generated by the first light source into the light transmission assembly for transmission to the endoscope. The second hemispherical reflector can be configured to redirect light generated by the second light source into the light transmission assembly for transmission to the endoscope. The stroboscopic endoscope system can further include an image processor configured to perform color balancing of images captured via the endoscope to compensate for a shift in spectrum induced by the first hemispherical reflector and the second hemispherical reflector. In some embodiments, each of the first light source and the second light source include a phosphor coating configured to emit white light.

The stroboscopic endoscope system can include a first total internal reflector and a second total internal reflector. The first total internal reflector can be configured to redirect light generated by the first light source into the light transmission assembly via total internal reflection for transmission into the light guide. The second total internal reflector configured to redirect light generated by the second light source into the light transmission assembly via total internal reflection for transmission into the light guide.

Each of the first light source and the second light source can be configured to generate monochromatic light. The light transmission assembly can include ceramic phosphors. In some embodiments, the sequence of light flashes excite the ceramic phosphors so as to generate a sequence of white light flashes that are transmitted to the endoscope. In some embodiments, the ceramic phosphors are excited in a reflective mode. In some embodiments, the ceramic phosphors are excited in a transmissive mode.

In another aspect, a stroboscopic endoscope system includes an endoscope, an imaging device, a first light source, a light transmission assembly, a heat sink, a thermoelectric cooler, and a controller. The endoscope includes a light guide The imaging device is configured for imaging an object illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the first light source into the light guide. The heat sink is coupled with the first light source to transfer heat generated by the first light source to the heat sink. The thermoelectric cooler is coupled with the heat sink and operable to remove heat from the heat sink. The controller is operative coupled with the first light source and the thermoelectric cooler. The controller is configured to energize the first light source to generate a sequence of light flashes. The controller is configured to operate the thermoelectric cooler to cool the heat sink to below an ambient temperature of air surrounding the heat sink prior to energizing the first light source to generate the sequence of light flashes.

The heat sink can be cooled to any suitable temperature below the ambient temperature. For example, in some embodiments, the heat sink is cooled to at least 5 degrees Celsius below the ambient temperature. In some embodiments, the heat sink is cooled to at least 10 degrees Celsius below the ambient temperature.

As a result of the precooling of heat sink prior to energizing the first light source to generate the sequence light, the first light source can be energized at a higher power while maintaining a suitable operational life expectancy due to increased cooling of the first light source. For example, in some embodiments, the first light source has a maximum recommended power level for continuous energization, a stroboscopic power level is intermittently applied to the first light source to generate the sequence of light flashes, and the stroboscopic power level is at least four times the maximum recommended power level. In some embodiments, the stroboscopic power level is at least eight times the maximum recommended power level.

The stroboscopic endoscope system can include any suitable number of LEDs that are intermittently energized to generate the sequence of light flashes. For example, in many embodiments, the stroboscopic endoscope system includes a second light source. The heat sink can be coupled with the second light source to transfer heat generated by the second light source to the heat sink. The controller can be configured to energize the second light source in conjunction with the first light source to generate the sequence of light flashes.

The stroboscopic endoscope system can be configured to increase the amount of light that is generated by the first light source (and by the second light source when included) that is emitted by the endoscope. For example, the stroboscopic endoscope system can further include a hemispherical reflector configured to redirect light generated by the first light source into the light transmission assembly for transmission into the light guide. In some embodiments, the stroboscopic endoscope system can include an image processor configured to perform color balancing of images captured via the endoscope to compensate for a first shift in spectrum induced by the first hemispherical reflector. In some embodiments, the first light source comprises a phosphor coating configured to emit white light. The stroboscopic endoscope system can further include a total internal reflector configured to redirect light generated by the first light source into the light transmission assembly via total internal reflection for transmission into the light guide.

The first light source (and the second light source when included) can have any suitable configuration. For example, in many embodiments, the first light source is configured to generate monochromatic light, the light transmission assembly can include ceramic phosphors, and the sequence of light flashes excite the ceramic phosphors so as to generate a sequence of white light flashes that are transmitted into the light guide. In some embodiments, the ceramic phosphors are excited in a reflective mode. In some embodiments, the ceramic phosphors are excited in a transmissive mode.

In another aspect, a method of capturing stroboscopic images includes operating a thermoelectric cooler to cool a heat sink to below an ambient temperature of air surrounding the heat sink. Subsequent to the heat sink being cooled to below the ambient temperature, a first light source is energized to generate a sequence of light flashes. The first light source is thermally coupled to the heat sink to cool the first light source during the generation of the sequence of light flashes. Light from the sequence of light flashes is transmitted into a light guide of an endoscope. Light from the sequence of light flashes is emitted by the endoscope. Images of an object illuminated by the light emitted by the endoscope are captured.

In many embodiments of the method, the heat sink is cooled to at least 5 degrees Celsius below the ambient temperature. In some embodiments of the method, the heat sink is cooled to at least 10 degrees Celsius below the ambient temperature.

In many embodiments of the method, the first light source is energized using a power level substantially higher than a continuous operation power level. For example, in many embodiments, the first light source has a maximum recommended power level for continuous operation, a stroboscopic power level is intermittently applied to the first light source to generate the sequence of light flashes, and the stroboscopic power level is at least four times the maximum recommended power level. In some embodiments of the method, the stroboscopic power level is at least eight times the maximum recommended power level.

In many embodiments of the method, two or more LEDs are energized to generate the sequence of light flashes. For example, in many embodiments of the method, subsequent to the heat sink being cooled to below the ambient temperature, a second light source is energized in conjunction with the first light source to generate the sequence of light flashes. The second light source can be thermally coupled to the heat sink to cool the second light source during the generation of the sequence of light flashes.

In many embodiments of the method, some of the light generated by the first light source that would not otherwise be directed so as to be transmitted through and emitted by the endoscope is redirected so as to be transmitted through and emitted by the endoscope, thereby increasing the percentage of the light generated by the first light source that is emitted by the endoscope instead of being wasted. For example, in some embodiments, the method includes redirecting light generated by the first light source by a hemispherical reflector for transmission into the light guide. In some embodiments, the method includes performing color balancing of images captured via the endoscope by an image processor to compensate for a first shift in spectrum induced by the hemispherical reflector. In some embodiments of the method, the first light source includes a phosphor coating configured to emit white light. In some embodiments, the method includes redirecting light generated by the first light source via total internal reflection for transmission into the light guide.

The first light source (and the second light source when included) can have any suitable configuration. For example, in many embodiments of the method, the first light source is configured to generate monochromatic light, the light transmission assembly can include ceramic phosphors, and the sequence of light flashes excite the ceramic phosphors so as to generate a sequence of white light flashes that are transmitted into the light guide. In some embodiments of the method, the ceramic phosphors are excited in a reflective mode. In some embodiments of the method, the ceramic phosphors are excited in a transmissive mode.

In another aspect, a stroboscopic endoscope system includes an endoscope, an imaging device, a first light source, a light transmission assembly, a hemispherical reflector, and a controller. The endoscope includes a light guide. The imaging device is configured for imaging an object illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the first light source into the light guide. The hemispherical reflector is configured to redirect light generated by the first light source into the light transmission assembly for transmission into the light guide. The controller is operative coupled with the first light source. The controller is configured to energize the first light source to generate a sequence of light flashes.

In another aspect, a stroboscopic endoscope system includes an endoscope, an imaging device, a first light source, a light transmission assembly, a total internal reflector, and a controller. The endoscope includes a light guide. The imaging device is configured for imaging an object illuminated via the endoscope. The light transmission assembly is configured to transmit light generated by the first light source into the light guide. The total internal reflector is configured to redirect light generated by the first light source via total internal reflection for transmission into the light guide. The controller is operative coupled with the first light source. The controller is configured to operate the first light source to generate a sequence of light flashes.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the ensuing detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** diagrammatically illustrates a stroboscopic endoscope system, in accordance with embodiments.

FIG. **2** diagrammatically illustrates an embodiment of the illumination/imaging subsystem of FIG. **1**.

FIG. **3** diagrammatically illustrates an embodiment of a stroboscopic light assembly that can be employed in the illumination/imaging subsystem of FIG. **1**.

FIG. **4** diagrammatically illustrates another embodiment of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIG. **5** diagrammatically illustrates another embodiment of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIG. **6** diagrammatically illustrates another embodiment of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIGS. **7**A and **7**B diagrammatically illustrate other embodiments of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIGS. **8** and **9** illustrate another embodiment of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIGS. **10**, **11**, and **12** illustrate another embodiment of a stroboscopic light assembly that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIG. **13** is a simplified schematic diagram of a method of capturing stroboscopic images that can be employed in the stroboscopic endoscope system of FIG. **1**.

FIGS. **14**A through **16**D illustrate an approach that can be employed in the stroboscopic endoscope system of FIG. **1** in which multiple illumination light pulses are emitted onto vocal cords of a patient during a video frame to increase the total amount of illumination light.

FIG. **17** is a simplified schematic diagram of a method of setting light pulse durations that can be employed in the approach of FIGS. **14**A through **16**D.

DETAILED DESCRIPTION

In the following description, various embodiments of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

Embodiments described herein are directed to a stroboscope (e.g., a laryngeal stroboscope) with LED generated stroboscopic light source. In some embodiments, the stroboscope is a laryngeal stroboscope is configured to provide stroboscopic illumination of a phonating larynx during imaging of the larynx by an electronic camera and ridged or flexible Laryngeal Scope. In preferred embodiments, the pulse timing of the stroboscopic light is controlled to synchronize each pulse with a video frame of the electronic camera and a derived fundamental frequency of the sound produced by the phonating larynx (e.g., obtained by a laryngeal microphone) in such a way as to provide apparent slow motion video of the larynx for review by a treating professional. In preferred embodiments, the system that presents the final strobe image has the capability to provide automatic color balancing in order to provide a high quality image for clinical use.

Turning now to the drawing figures, in which like reference numbers refer to like elements in the various figures, FIG. **1** diagrammatically illustrates a stroboscopic endoscope system **10**, in accordance with embodiments, being used for imaging of a phonating larynx of a patient **12**. The stroboscopic endoscope system **10** includes an endoscope **14**, a laryngeal microphone **16**, an illumination/imaging subsystem **18**, and a display **20**. In the illustrated configuration, the laryngeal microphone **16** is interfaced with the throat of the patient **12** near the larynx for detecting the patient's vocalization (e.g., speech, singing, certain tones as requested by the medical professional conducting the examination) during imaging of the phonating larynx. The laryngeal microphone **16** can, however, be mounted at any suitable location for detecting the patient's vocalization. In the illustrated configuration, the endoscope **14** is shown positioned for illuminating the larynx with stroboscopic light emitted from the endoscope **14** and generating image data of the larynx. The endoscope **14** is connected to the illumination/imaging subsystem **18** by a suitable cable **22** via which the illumination/imaging subsystem **18** transmits a stroboscopic sequence of light flashes to the endoscope **14** for emission by the endoscope **14** to illuminate the larynx and receives image data from an endoscope imaging device included in the endoscope **14**. The laryngeal microphone **16** is connected to the illumination/imaging subsystem **18** via a suitable microphone cable **24** for receiving audio data or output signal generated by the laryngeal microphone **16**.

The illumination/imaging subsystem **18** includes a stroboscopic light assembly that includes one or more light emitting diodes (LEDs) that are controllably energized to generate the sequence of light flashes based on the output of the laryngeal microphone **16** so as to synchronize the light flashes with a base frequency of the phonating larynx. In many embodiments, the cable **22** includes a flexible light guide (e.g., a flexible optical cable including one or more optical fibers) and light generated by the one or more LEDs is coupled into the flexible light guide. The flexible light guide transmits the sequence of light flashes to the endoscope **14**, which emits the stroboscopic light to intermittently illuminate the phonating larynx.

In many embodiments, the illumination/imaging subsystem **18** process the image data received from the endoscope

14 to generate apparent slow motion video of the larynx for review by a treating professional. In preferred embodiments, the illumination/imaging subsystem **18** performs automatic color balancing in order to provide a high quality image for clinical use. In the illustrated embodiments, the illumination/imaging subsystem **18** is operable to display the apparent slow motion video of the larynx on the display **20**.

FIG. **2** diagrammatically illustrates an embodiment of the illumination/imaging subsystem **18** of FIG. **1**. In the illustrated embodiment, the illumination/imaging subsystem **18** includes a base/illumination unit **26**, a camera control unit **28**, a video processing unit **30**, a video capture module **32**, a lapel microphone **34**, the laryngeal microphone **16**, a foot pedal **36**, and an isolation power transformer **38**. The base/illumination unit **26** processes output generated by the laryngeal microphone **16** to determine and track the base frequency of the vocalization of the patient **12**. The base/illumination unit **26** includes one or more LEDs to generate a stroboscopic sequence of light flashes by intermittently energizing the one or more LEDs based on the tracked based frequency to sequentially illuminate the larynx at a progressing sequence of stages of the larynx during the vibration of the larynx. The camera control unit **28** controls operation of the endoscope imaging device of the endoscope **14** and provides video of the phonating larynx to the base/illumination unit **26**. The video processing unit **30** processes image data generated by the endoscope imaging device and provides the processed video to the base/illumination unit **26**. Video input supplied to the base/illumination unit **26** by the camera control unit **28** and/or by the video processing unit **30** is output to the video capture module **32**. The base/illumination unit **26** also outputs an audio output to the video capture module **32**. The audio output provided to the video capture module **32** can include an audio output generated by the lapel microphone **34** and/or an audio output generated by the laryngeal microphone **16** for the purpose of context to video of the phonating larynx captured by the endoscopic system **10**. The video capture module **32** is configured to generate and store the apparent slow motion video of the larynx for review by a treating professional.

The base/illumination unit **26** can include one or more LEDs that are overdriven (relative to the corresponding manufacturer's maximum power level for the LED(s)) to produce short (e.g., nominal 120 us) intense white light pulses (e.g., with a repetition rate of 60 pulses per second) used to "freeze" the motion of the phonating larynx. In some envisioned embodiments, the LED(s) are overdriven by 4 to 12 times the manufacturer's maximum power level for the LED(s). The overdriving of the LED(s) may be further characterized in terms of a ratio of instantaneous power applied to the LED(s) to light emitting area of the LED(s). In some envisioned embodiments, the ratio of instantaneous power applied to the LED(s) to light emitting area of the LED(s) is 4 to 12 times a ratio corresponding to the manufacturer's maximum power level for the LED(s). In some embodiments, the LED(s) are blue LASER Diodes(s) that generate 450 nm wavelength light used to excite ceramic phosphors to produce the white light. In some embodiments, the LED(s) are LASER Diodes(s). In many embodiments, the LED(s) generate non-collimated light.

The base/illumination unit **26** can include a cooling mechanism used to pre-cool the LED(s) and/or an associated heat sink thermally coupled with the LED(s) prior to an imaging session. For example, in some envisioned embodiments, the base/illumination unit **26** includes a Peltier heat pump (aka, thermoelectric cooler), which can be used to pre-cool the LED(s) below ambient temperatures and/or a heat sink thermally coupled with the LED(s).

Stroboscopic Light Assemblies

In many embodiments, the stroboscopic light assembly of the base/illumination unit **26** is configured to accommodate the application of higher power to the one or more LEDs via precooling of a heat sink coupled with the one or more LEDs. In many embodiments, the stroboscopic light assembly includes a light redirection assembly that redirects some of the light generated by the one or more LEDs that would not otherwise be directed so as to be transmitted through and emitted by the endoscope so as to be transmitted through and emitted by the endoscope, thereby increasing the percentage of the light generated by the one or more LEDs that is emitted by the endoscope instead of being wasted. In many embodiments, both the precooling of the heat sink and the light redirection assembly are employed.

The LED(s) can be blue LASER Diodes that excite ceramic phosphors so as to cause the ceramic phosphors to emit white light flashes for emission by the endoscope **14** to illuminate a phonating larynx. For example, in some embodiments the LED(s) can be blue LASER Diodes that excite ceramic phosphors in a reflective mode as illustrated in FIG. **3**.

FIG. **3** diagrammatically illustrates a stroboscopic light assembly **100** that can be included in the base/illumination unit **26**. The light assembly **100** includes LEDs **102**, **104**, **106**, a heat sink **108**, a thermoelectric cooler **110**, a heat exchanger **112**, an endoscopic light guide **114**, and a light coupling assembly **116**. The LEDs **102**, **104**, and **116** are intermittently and concurrently energized to generate a sequence of light flashes that are coupled into the endoscopic light guide **114** by the light coupling assembly **116**.

The light coupling assembly **116** includes lenses **118**, **120** and reflective phosphor assembly **122**. The reflective phosphor assembly **122** has a reflective surface **124** and a phosphor coating **126** on the reflective surface **124**. In the illustrated embodiment, the LEDs **102**, **104**, **106** emit a sequence of 450 nm wavelength light flashes **128**. The lens **118** focuses 450 nm wavelength light flashes **128** emitted by the LEDs **102**, **104**, **106** onto the phosphor coating **126**. The phosphor coating **126** is excited by the 450 nm light flashes **128** and thereby emits a sequence of white light flashes **130**. The reflective surface **124** reflects some of the white light flashes **130** emitted by the phosphor coating **126** towards the lens **120**. Accordingly, the phosphor coating **126** is excited in a reflective mode. The lens **120** focuses much of the white light flashes **130** emitted by the phosphor coating **126** into the endoscopic light guide **114**. The endoscopic light guide **114** transmits the white light flashes **130** to the endoscope **14**, which emits the white light flashes **130** to illuminate the phonating larynx.

The LEDs **102**, **104**, **106** are thermally coupled with the heat sink **108** so that heat generated by the LEDs **102**, **104**, **106** during the intermittent energization of the LEDs **102**, **104**, **106** is transferred to the heat sink **108** via thermal conduction, thereby serving to increase cooling of the LEDs so that the LEDs can be energized at higher power levels as compared to lesser cooling of the LEDs. The thermoelectric cooler **110** is operable to transfer heat from the heat sink **108** to the heat exchanger **112**. The heat exchanger **112** is configured to transfer heat to a suitable repository (e.g., ambient air, a suitable liquid coolant). In many embodiments, the thermoelectric cooler **110** is operated prior to energization of the LEDs **102**, **104**, **106** so as to cool the heat sink below the ambient temperature of air surrounding the heat sink **108** and/or the LEDs **102**, **104**, **106** prior to energizing the LEDs **102**, **104**, **106** to generate the sequence of light flashes. In some embodiments, the thermoelectric cooler **110** continues to be operated during the energization of the LEDs **102**, **104**, **106** to reduce the rate at which the temperature of the heat sink **108** increases during the energization of the LEDs **102**, **104**, **106**. Junction temperatures reduction of up to 15 C for a single stage Peltier increasing heat transfer from the LED are maintainable.

FIG. **4** diagrammatically illustrates a stroboscopic light assembly **200** that can be included in the base/illumination unit **26**. The light assembly **200** includes LEDs **202**, **204**, **206**, a heat sink **208**, a thermoelectric cooler **210**, a heat exchanger **212**, an endoscopic light guide **214**, and a light coupling assembly **216**. The LEDs **102**, **104**, and **116** are intermittently and concurrently energized to generate a sequence of light flashes that are coupled into the endoscopic light guide **214** by the light coupling assembly **216**.

The light coupling assembly **216** includes a lens **218** and transmissive phosphor assembly **220**. The transmissive phosphor assembly **220** has a transmissive element **222** and a phosphor coating **224** on the transmissive element **222**. In the illustrated embodiment, the LEDs **202**, **204**, **206** emit a sequence of 450 nm wavelength light flashes **226**. The lens **218** focuses 450 nm wavelength light flashes **226** emitted by the LEDs **202**, **204**, **206** onto the phosphor coating **224**. The phosphor coating **224** is excited by the 450 nm light flashes **226** and thereby emits a sequence of white light flashes **230**. The some of the white light flashes **230** emitted by the phosphor coating **224** are transmitted through the transmissive element **222** into the endoscopic light guide **214**. Accordingly, the phosphor coating **224** is excited in a transmissive mode. The endoscopic light guide **214** transmits the white light flashes **230** to the endoscope **14**, which emits the white light flashes **230** to illuminate the phonating larynx.

The LEDs **202**, **204**, **206** are thermally coupled with the heat sink **208** so that heat generated by the LEDs **202**, **204**, **206** during the intermittent energization of the LEDs **202**, **204**, **206** is transferred to the heat sink **208** via thermal conduction, thereby serving to increase cooling of the LEDs so that the LEDs can be energized at higher power levels as compared to lesser cooling of the LEDs. The thermoelectric cooler **210** is operable to transfer heat from the heat sink **208** to the heat exchanger **212**. The heat exchanger **212** is configured to transfer heat to a suitable repository (e.g., ambient air, a suitable liquid coolant). In many embodiments, the thermoelectric cooler **210** is operated prior to energization of the LEDs **202**, **204**, **206** so as to cool the heat sink below the ambient temperature of air surrounding the heat sink **208** and/or the LEDs **202**, **204**, **206** prior to energizing the LEDs **202**, **204**, **206** to generate the sequence of light flashes. In some embodiments, the thermoelectric cooler **210** continues to be operated during the energization of the LEDs **202**, **204**, **206** to reduce the rate at which the temperature of the heat sink **208** increases during the energization of the LEDs **202**, **204**, **206**.

FIG. **5** diagrammatically illustrates a stroboscopic light assembly **300** that can be included in the base/illumination unit **26**. The light assembly **300** includes a phosphor coated blue LED **302**, a reflective base **304**, a hemispherical reflector **306**, and a light coupling assembly **308**. The phosphor coated blue LED **302** is mounted to the reflective base. The LED **302** is intermittently energized to generate a sequence of white light flashes that is coupled into the endoscope **14**. In many embodiments, the reflective base **304** functions as a heat sink to absorb heat generated by the LED **302**. In many embodiments, the light assembly **300** includes a thermoelectric cooler and heat exchanger as described herein in any of the light assemblies **100**, **200** for precooling the reflective base **304**.

The sequence of white light flashes emitted by the LED **302** is transmitted into the endoscope **14** via the reflective base **304**, the hemispherical reflector **306**, and the light coupling assembly **308**. The reflective base **304** and the hemispherical reflector **306** are configured to redirect portions of the sequence of white light flashes emitted by the LED **302** that would not otherwise be incident onto the lens **310** so as to be incident on the lens **310**, thereby increasing the amount of light from the sequence of white light flashes emitted by the LED **302** that is coupled into the endoscope **14**. The video processing unit **30** can have the capability to automatically color balance for a shift in spectrum induced by the hemispherical reflector **306**.

FIG. **6** diagrammatically illustrates a stroboscopic light assembly **400** that can be included in the base/illumination unit **26**. The light assembly **400** aggregates two of the light assemblies **300**.

FIG. **7**A diagrammatically illustrates a stroboscopic light assembly **500** that can be included in the base/illumination unit **26**. The light assembly **500** includes a phosphor coated blue LED **502**, a reflective base **504**, a Total Internal Reflection (TIR) optical element **506**, and a lens **508**. The phosphor coated blue LED **502** is mounted to the reflective base **504**. The LED **502** is intermittently energized to generate a sequence of white light flashes that is coupled into the endoscope **14**. In many embodiments, the reflective base **504** functions as a heat sink to absorb heat generated by the LED **502**. In many embodiments, the light assembly **500** includes a thermoelectric cooler and heat exchanger as described herein in any of the light assemblies **100**, **200** for precooling the reflective base **504**.

The sequence of white light flashes emitted by the LED **302** is transmitted into the endoscope **14** via the reflective base **504**, the TIR optical element **506**, and the lens **508**. The reflective base **504** and the TIR optical element **506** are configured to redirect portions of the sequence of white light flashes emitted by the LED **502** that would not otherwise be incident onto the lens **508** so as to be incident on the lens **508**, thereby increasing the amount of light from the sequence of white light flashes emitted by the LED **502** that is coupled into the endoscope **14**. The TIR optical element **506** is externally shaped to redirect light emitted by the LED **502** onto the lens **508** via total internal reflection of the light within the TIR optical element **506**.

FIG. **7**B depicts an alternate stroboscopic light assembly **500**B embodiment that can be included in the base/illumination unit **26**. The light assembly **500**B includes a reflective light transmitter (RLT) **532**, an LED light source **502**, a heat sink **534**, alignment pins **536**, focus carriage **538**, and a central lens module **508** with a collimating lens and a converging lens. This embodiment enables alignment of a light source such as LED **502** to the scope light guide, and may include fiber port **540**. X and Y dimensions with respect to the optical axis (Z) are handled with a mechanical light engine module **520**. The Z axis alignment may vary for scopes from different manufacturers. In some embodiments, Z axis alignment may be manual, with electro-mechanical adjustment under front panel controls, or a mechanical adjustment wheel. When electro-mechanical adjustment occurs, it may be an automatic adjustment using a Proportional Integral Derivative (PID) on the video input to optimize for maximum brightness. The automatic adjustment may further also be either as a setup function or a period adjustment used to optimize the field of illumination.

FIGS. **8** and **9** illustrate a stroboscopic light assembly **600** that can be included in the base/illumination unit **26**. The light assembly **600** includes four reflective light transmitters (RLTs) **602**, a central LED **604**, a central collimating lens **606**, and a shared converging lens **608**. Each of the four RLTs **602** includes a reflective base **610**, a hemispherical reflector **612**, an LED **614**, and a collimating lens **616**. The hemispherical reflector **612** has a central aperture **618** through which light emitted by the LED **614** is transmitted to the collimating lens **616**. Light emitted by the LED **614** onto the hemispherical reflector **612** or the reflective base **610** redirected by the hemispherical reflector **612** and/or the reflective base **610** so as to increase the amount of light emitted by the LED **614** that propagates through the collimating lens **616**. The collimating lens **616** is configured to redirect the light emitted by the LED **614** to the shared converging lens **608**. The shared converging lens **608** is configured to redirect the light from each of the four RLTs **602** into an endoscopic light guide **620**. To reduce an overall diameter of the combination of the four RLTs **602**, two of the RLTs **602** are arranged on a first plane and the other two of the RLTs **602** are arranged on a second plane offset from the first plane so as to accommodate overlapping of the hemispherical reflectors **612** (shown in FIG. **10**) without overlapping of the central collimating lenses **606**. The light assembly **600** provides increased light output as a result of the use of 5 total LEDs. The spatial distribution of the four RLTs **602** and the central location of the central LED **604** provides for increased uniformity in the intensity of light transmitted into a light acceptance cone of the light guide **620**, thereby increasing uniformity in the distribution of light emitted by the endoscope onto the phonating vocal cords.

FIGS. **10**, **11**, and **12** illustrate a stroboscopic light assembly **700** that can be included in the base/illumination unit **26**. The light assembly **700** includes seven total internal reflection (TIR) transmitters **702** and a shared converging lens **704**. The seven TIR transmitters **702** are arranged in a common plane with a center TIR transmitter **702** surrounded by a hexagonal arrangement of the remaining six TIR transmitters **702**. Each of the TIR transmitters **702** include a phosphor coated blue LED **706**, a reflective base **708**, a TIR optical element **710**. The phosphor coated blue LED **706** is mounted to the reflective base **708**. The LED **702** is intermittently energized to generate a sequence of white light flashes that is coupled into an endoscope light guide **712**. In many embodiments, the reflective base **708** functions as a heat sink to absorb heat generated by the LED **706**. In many embodiments, the light assembly **700** includes a thermoelectric cooler and heat exchanger as described herein in any of the light assemblies **100**, **200** for precooling the reflective base **708**.

The sequence of white light flashes emitted by each of the LEDs **706** is transmitted into the endoscope light scope **712** via the reflective base **708**, the TIR optical element **710**, and the shared converging lens **704**. The reflective base **708** and the TIR optical element **710** are configured to redirect portions of the sequence of white light flashes emitted by the LED **706** that would not otherwise be incident onto the shared converging lens **704** so as to be incident on the lens **704**, thereby increasing the amount of light from the sequence of white light flashes emitted by the LED **706** that is coupled into the endoscope **14**. The TIR optical element **710** is externally shaped to redirect light emitted by the LED **706** onto the lens **704** via total internal reflection of the light within the TIR optical element **710**. The light assembly **700** provides increased light output as a result of the use of 7 total LEDs. The spatial distribution of the seven TIR transmitters **702** provides for increased uniformity in the intensity of light transmitted into a light acceptance cone of the light guide **712**, thereby increasing uniformity in the distribution of light emitted by the endoscope onto the phonating vocal cords.

FIG. **13** is a simplified schematic diagram of a method **800** of capturing stroboscopic images, in accordance with embodiments. The method **800** can be accomplished using any suitable stroboscopic imaging system, such as the stroboscopic endoscope system **10** described herein. The method **800** includes acts **802**, **804**, **806**, **808**, and **810**. In act **802**, a heat sink is cooled below an ambient temperature. In act **804**, one or more LEDs are energized to generate a sequence of light flashes. The one or more LEDs are thermally coupled with the heat sink so that heat generated by the one or more LEDs is transferred to the heat sink via heat conduction, thereby cooling the one or more LEDs. In many embodiments, the cooling of the one or more LEDs is used to accommodate the use of increased power applied to the one or more LEDs while maintaining an expected service life of the one or more LEDs. In act **806**, light from the sequence of light flashes is transmitted to an endoscope. In many embodiments, a light redirecting component (e.g., hemispherical reflector, TIR optical element) is used to increase the amount of light from the sequence of light flashes that is transmitted to the endoscope. In act **808**, light from the sequence of light flashes is emitted by the endoscope. In act **810**, images are captured of an object (e.g., a phonating larynx) illuminated by the light emitted by the endoscope.

FIGS. **14**A through **16**D illustrate an approach that can be employed in the stroboscopic endoscope system **10** in which multiple illumination light pulses are emitted onto vocal cords of a patient during each of any suitable and applicable video frame to increase the total amount of illumination light. When a 60 frame/second video frame rate is employed, each video frame has a duration of 16.6 ms. For all patient fundamental phonation frequencies of at least 120 Hz, there are at least two complete cycles of vocal cord displacement phases that occurs during each video frame. For all patient fundamental phonation frequencies less than 120 Hz, there are less than two complete cycles of vocal cord displacement phases that occurs during each video frame.

For example, FIGS. **14**A, **14**B, **14**C, and **14**D illustrate four separate video frames selected from a sequence of video frames of video with a 60 frame/second video frame rate and a patient fundamental phonation frequency of 60 Hz, which produces one complete cycle of vocal cord displacement phases per video frame. A trace **902** represents cyclical changes of the vocal cord displacement phases in each of the FIGS. **14**A through **16**D. When a video frame covers less than two complete cycles of vocal cord displacement phases, a single illumination pulse **904** can be emitted during the video frame to illuminate a phase of the vocal cord displacement for illumination via the video frame. A sequence of video frames can then be used to target a sequence of different phases of the vocal cord displacement via corresponding timing of the respective illumination pulses **904** as illustrated in the four video frames shown. The duration of the single illumination pulse **904** can be limited in duration so as to suitable for use with patient fundamental frequencies up to 120 Hz without resulting in blurring of the image captured in the video frame resulting from the changing of the phase of vocal cord displacement during the single illumination pulse **904**. For example, in the illustrated embodiment, the single illumination pulse **904** has a duration of 300 us.

FIGS. **15**A, **15**B, **15**C, and **15**D illustrate four separate video frames selected from a sequence of video frames of video with a 60 frame/second video frame rate and a patient fundamental phonation frequency of 120 Hz, which produces two complete cycle of vocal cord displacement phases per video frame. When a video frame covers at least two complete cycles of vocal cord displacement phases, two illumination pulses **906** can be emitted during the video frame to separately illuminate the vocal cords at matching phases of the vocal cord displacement for illumination via the video frame. A sequence of video frames can then be used to target a sequence of different phases of the vocal cord displacement via corresponding timing of the respective sets of the two illumination pulses **906** as illustrated in the four video frames shown. The duration of each of the two illumination pulses **906** can be limited in duration so as to suitable for use with patient fundamental frequencies up to 180 Hz without resulting in blurring of the image captured in the video frame resulting from the changing of the phase of vocal cord displacement during the illumination pulse **906**. For example, in the illustrated embodiment, each illumination pulse **906** has a duration of 150 us, which is one-half of the 300 us duration of the single illumination pulse **904**, thereby supplying the same total illumination via the two 150 us illumination pulses **906** as for the single 300 us illumination pulse **904**.

FIGS. **16**A, **16**B, **16**C, and **16**D illustrate four separate video frames selected from a sequence of video frames of video with a 60 frame/second video frame rate and a patient fundamental phonation frequency of 340 Hz, which produces about 5.67 complete cycle of vocal cord displacement phases per video frame. When a video frame covers at least three complete cycles of vocal cord displacement phases, three illumination pulses **908** can be emitted during the video frame to separately illuminate the vocal cords at matching phases of the vocal cord displacement for illumination via the video frame. A sequence of video frames can then be used to target a sequence of different phases of the vocal cord displacement via corresponding timing of the respective sets of the three illumination pulses **908** as illustrated in the four video frames shown. The duration of each of the three illumination pulses **908** can be limited in duration so as to suitable for use without resulting in blurring of the image captured in the video frame resulting from the changing of the phase of vocal cord displacement during the illumination pulse **908**. For example, in the illustrated embodiment, each illumination pulse **908** has a duration of 100 us, which is one-third of the 300 us duration of the single illumination pulse **904**, thereby supplying the same total illumination via the three 100 us illumination pulses **908** as for the single 300 us illumination pulse **904**.

FIG. **17** is a simplified schematic diagram of a method **1000** of setting light pulse durations that can be employed in the approach of FIGS. **14**A through **16**D. In act **1002**, a maximum light pulse duration suitable for use with a maximum phonation frequency that results in less than two complete cycles of vocal cord displacement phases per video frame is determined so to avoid blurring of the image captured in the video frame resulting from the changing of the phase of vocal cord displacement during the single illumination pulse **904**. In act **1004**, a one-cycle pulse duration can be set to be equal or less than the maximum light pulse duration determined in act **1002**. For example, the example single illumination pulse **904** has a 300 us duration. In act **1006**, a two-cycle pulse duration can be set to one-half of the one-cycle pulse duration determined in act **1004**. In act **1008**, a three-cycle pulse duration can be set to one-third of the one-cycle pulse duration determined in act **1004**. In act **1010**, a four-cycle pulse duration can be set to one-fourth of the one-cycle pulse duration determined in act **1004**. A single illumination pulse can be emitted per video frame up to any suitable maximum phonation frequency for which the one-cycle pulse duration is sufficiently short to avoid blurring of the video frame image. Two illumination pulses can be emitted per video frame where the video frame encompasses at least two complete cycles of vocal cord phases up to any suitable maximum phonation frequency for which the two-cycle pulse duration is sufficiently short to avoid blurring of the video frame image. Three illumination pulses can be emitted per video frame where the video frame encompasses at least three complete cycles of vocal cord phases up to any suitable maximum phonation frequency for which the three-cycle pulse duration is sufficiently short to avoid blurring of the video frame image. Four illumination pulses can be emitted per video frame where the video frame encompasses at least four complete cycles of vocal cord phases up to any suitable maximum phonation frequency for which the four-cycle pulse duration is sufficiently short to avoid blurring of the video frame image.

Other variations are within the spirit of the present invention. Thus, while the invention is susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the invention to the specific form or forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the invention, as defined in the appended claims.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. The term "connected" is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

1. A stroboscopic endoscope system, comprising:

an endoscope comprising a light guide;

a video device configured for imaging vocal chords of a patient that are illuminated via the endoscope;

a first light source;

a light transmission assembly configured to transmit light generated by the first light source into the light guide;

a microphone configured to generate a microphone output signal in response to vocalization of the patient;

a controller operative coupled with the first light source, the video device, and the microphone; wherein the controller is configured to process the microphone output signal to track a fundamental phonation frequency of the patient, wherein the controller is configured to energize the first light source to generate a sequence of two or more light flashes in synchronization with the fundamental phonation frequency during a first video frame of the video device during which the vocal chords complete at least two complete displacement cycles so that the sequence of two or more light flashes illuminate matching segments of the at least two complete displacement cycles;

wherein the sequence of two or more light flashes during the first video frame consists of one of the following:

two light flashes, wherein each of the two light flashes has a duration equal to one-half of a single light flash duration of a single light flash of a different video frame;

three light flashes, wherein each of the three light flashes has a duration equal to one-third of a single light flash duration of a single light flash of a different video frame; or

four light flashes, wherein each of the four light flashes has a duration equal to one-fourth of a single light flash duration of a single light flash of a different video frame.

2. The stroboscopic endoscope system of claim **1**, wherein:

the controller is further configured to energize the first light source to generate a single light flash in synchronization with the fundamental phonation frequency during a second video frame of the video device during which the vocal chords complete less than two complete displacement cycles so that the single light flash illuminates a selected segment of one displacement cycle of the less than two complete displacement cycles; and

the single light flash has a single light flash duration.

3. The stroboscopic endoscope system of claim **2**, wherein the controller is further configured to energize the first light source to generate a sequence of three or more light flashes in synchronization with the fundamental phonation frequency during a third video frame of the video device during which the vocal chords complete at least three complete displacement cycles so that the sequence of three or more light flashes illuminate matching segments of the at least three complete displacement cycles.

4. The stroboscopic endoscope system of claim **3**, wherein the controller is further configured to energize the first light source to generate a sequence of four or more light flashes in synchronization with the fundamental phonation frequency during a fourth video frame of the video device during which the vocal chords complete at least four complete displacement cycles so that the sequence of four or more light flashes illuminate matching segments of the at least four complete displacement cycles.

5. The stroboscopic endoscope system of claim **1**, further comprising:

a heat sink coupled with the first light source to transfer heat generated by the first light source to the heat sink; and

a thermoelectric cooler coupled with the heat sink and operable to remove heat from the heat sink,

wherein the controller is operative coupled with the thermoelectric cooler and configured to operate the thermoelectric cooler to cool the heat sink to below an ambient temperature of air surrounding the heat sink prior to energizing the first light source to generate the sequence of light flashes.

6. The stroboscopic endoscope system of claim **5**, wherein the heat sink is cooled to at least 5 degrees Celsius below the ambient temperature.

7. The stroboscopic endoscope system of claim **6**, wherein the heat sink is cooled to at least 10 degrees Celsius below the ambient temperature.

8. The stroboscopic endoscope system of claim **1**, further comprising a hemispherical reflector configured to redirect light generated by the first light source into the light transmission assembly for transmission into the light guide.

9. The stroboscopic endoscope system of claim **8**, further comprising an image processor configured to perform color balancing of images captured via the endoscope to compensate for a first shift in spectrum induced by the hemispherical reflector.

10. The stroboscopic endoscope system of claim **9**, wherein the first light source comprises a phosphor coating configured to emit white light.

11. The stroboscopic endoscope system of claim **1**, further comprising a total internal reflector configured to redirect light generated by the first light source into the light transmission assembly via total internal reflection for transmission into the light guide.

12. The stroboscopic endoscope system of claim **1**, wherein:

the first light source is configured to generate monochromatic light;

the light transmission assembly comprises ceramic phosphors; and

the sequence of light flashes excite the ceramic phosphors so as to generate a sequence of white light flashes that are transmitted into the light guide.

13. The stroboscopic endoscope system of claim **12**, wherein the ceramic phosphors are excited in a reflective mode.

14. The stroboscopic endoscope system of claim **12**, wherein the ceramic phosphors are excited in a transmissive mode.

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